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The Certified Six Sigma Yellow Belt Handbook Govind Ramu ASQ Quality Press Milwaukee, Wisconsin H1493 Ramu_p00i-284.indd 3 7/13/16 5:55 PM American Society for Quality, Quality Press, Milwaukee 53203 © 2017 by ASQ. Printed in 2016 All rights reserved. Printed in the United States of America 21 20 19 18 17 16 5 4 3 2 1 Library of Congress Cataloging-in-Publication Data Names: Ramu, Govindarajan, author. Title: The certified Six Sigma yellow belt handbook / Govindarajan Ramu. Description: Milwaukee : ASQ Quality Press, 2016. | Includes bibliographical references and index. 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Attention Bookstores, Wholesalers, Schools, and Corporations: ASQ Quality Press books, video, audio, and software are available at quantity discounts with bulk purchases for business, educational, or instructional use. For information, please contact ASQ Quality Press at 800-248-1946, or write to ASQ Quality Press, P.O. Box 3005, Milwaukee, WI 53201–3005. To place orders or to request a free copy of the ASQ Quality Press Publications Catalog, visit our website at . Printed on acid-free paper H1493 Ramu_p00i-284.indd 4 7/13/16 5:55 PM I thank my mom, Vasantha, for her unconditional love and encouragement. My dad, Ramu, would have been so proud to see this book come out. The morals and principles that he taught me keep me grounded. Thanks to my wife, Anitha, and my children, Vibha and Vivek, for their patience and sacrifice of countless evenings and weekends. Without their support, this book would not have been possible. H1493 Ramu_p00i-284.indd 5 7/13/16 5:55 PM Acknowledgments I would like to thank the numerous individuals who have taught me technical and management acumen, and hard and soft skills; have provided opportunities for me; and have been coaches and mentors to me. I would like to acknowledge Noel Wilson from the ASQ Knowledge Center for her guidance and support of my publications since 2006. Noel is an asset to ASQ and a gift to quality professionals like me. We all learn a lot from our managers. Over my 30 years in quality management I have had lots of bosses and I have learned a lot about critical thinking. My very first manager taught me attention to details. Another manager explained to me that when my requirement is one, learn to live with half. Another one famously repeated "check, recheck, and cross check." I learned to be empathetic to my colleagues and respectful to staff. 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I have always been fortunate to have managers who support my development. I would like to thank Quality Press staff Paul O'Mara and Matt Meinholz for their incredible patience, understanding, and support in this project, and John Noguera, CTO and cofounder of SigmaXL, Inc. I would also like to thank my coauthors from my previous publication on Six Sigma. I learned a lot working with Roderick Munro and Daniel Zrymiak on the second edition of The Certified Six Sigma Green Belt Handbook. Contents of that handbook provided a baseline for my authoring of The Certified Six Sigma Yellow Belt Handbook. I would like to thank the following Lean Six Sigma professionals who performed careful reviews at different stages of the book: S. Anilkumar, David S. Foxx, Eric Gemunder, and Chad Walters. Finally, there are many I am not addressing here. They all have my respect for their professionalism and continued support. xix H1493 Ramu_p00i-284.indd 19 7/19/16 5:35 PM List of Figures and Tables Part I Table 1.1 Mapping of PDCA with Six Sigma DMAIC model. . . . . 4 Table 1.2 Six Sigma tools overview by stage. . . . . 5 Table 1.3 Approaches to quality over the years . . . . 8 Figure 2.1 Common symbols used in value stream mapping . . . . 15 Figure 2.2 Value stream map example. . . . . 16 Figure 2.3 The 5S cycle. . . . . 17 Figure 2.4 5S workplace scan diagnostic checklist. . . . . 19 Figure 2.5 The 7S adaptation (Hirano). . . . . 20 Figure 2.6 Visual factory. . . . . 20 Figure 2.7 Examples of mistake proofing . . . . 22 Figure 2.8 A sea of inventory often hides unresolved problems. . . . . 25 Figure 2.9 C-shaped manufacturing cell. . . . . 26 Figure 3.1 Typical large Six Sigma organization. . . . . 29 Table 3.1 Typical Six Sigma roles. . . . . 30 Table 4.1 Common negative team dynamics and potential countermeasures. . . . . 39 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The sample questions are intended to represent the style of the exam questions and are offered for practice. Tools and templates Useful publications Worked out examples *Please see the CD-ROM for a complete listing of the contents in each folder. xv H1493 Ramu_p00i-284.indd 15 7/19/16 5:02 PM Introduction: The ASQ Certification Process T his section contains information about the exam process itself. Although not part of the exam material, this is useful information to give you background and help you understand the ASQ Certification process. You are encouraged to read this section. The Test Development Process Many exams, whether tests or certifications, are written by a very few professionals (sometimes only one person) based on what they think an examinee should know to meet the criteria of some training materials (like nearly all college exams). The American Society for Quality Control (ASQC changed its name to ASQ in 1997) started developing the Certified Quality Engineer (CQE) program in 1967, making it the oldest professional quality certification in the United States. ASQC gathered a small number of quality professionals together for the development cycle of the exam. The first CQE exam developers and a few others were grandfathered in, bypassing the taking of the first exam, which was offered in 1968. Throughout the 1970s and early 1980s ASQC and others developed more certification exams. During this time, the issue of what the difference is between a professional certification and a state license (for example, the Professional Engineers exam process) was being raised as some U.S. states and Canada started questioning the professional community about what they were doing. ASQC and other professional organizations started trying to distinguish certifications given by their organizations from state or other governmental certifications. Basically, one is granted by peer recognition (professional organizations), the other by a governmental licensing process. In response to this growing concern and the possibility of legal litigation as to the fairness of the exam process, ASQC wanted to become proactive about their certification process. After a benchmarking exercise and a search for what was considered the very best exam development process, ASQC partnered with the Educational Testing Service (ETS is the organization that creates and maintains the SAT exams for college-bound students). The two organizations worked together to develop an exam development process that would be legally defensible both in court and to the various governmental organizations who might choose to challenge the process. The ASQC CQE xxi H1493 Ramu_p00i-284.indd 21 7/13/16 5:55 PM xxii Introduction exam was the first to be redesigned with the new development process. The basic steps include: • Design of a survey to identify the current tools and methodologies being used in a wide breadth of industries across the United States. • Targeting ASQ members who are currently certified in a particular discipline, as well as managers and industry leaders who are aware of the needs in the various industry sectors across the country. • Tabulating the results of the most widely used tools, techniques, and methodologies to create a basic Body of Knowledge (BoK) for the new or redeveloped exam. • Coordinating exam-writing workshops around the BoK, paying special attention to the demographics of the exam question writers. Each industry and all parts of the country are ensured some participation in the exam-writing process. • During the exam-writing process the participants are broken up into teams. Each person writes a few questions based on their assigned portion of the BoK and then has two or more other team members review the question for accuracy, references, and fairness. • The team leader submits the questions to the exam-writing workshop lead person, who also reviews the questions. Others will then review anything that raises any issue at the workshop. • The questions are then entered into a proposed exam bank based on their relevance to the specified exam's BoK. • As enough questions are identified in the proposed exam bank, another workshop is called, with new reviewers to look over each question. The questions are accepted, reworked, or rejected for the BoK exam bank. • About six months before an exam is to be given, a sort of the exam bank is conducted to select a new exam (each exam is different from all other exams) with some alternate questions for each area of the BoK. This exam mockup is then presented to an exam review workshop. These participants review every question and discuss their attributes related to the BoK. At the end of this process the exam is set for the next offering. • Exams are prepared and distributed to testing centers or ASQ conferences where they will be administered to participants. • All exams are graded using the identified answers from the exam bank. Once all exams are graded, a statistical cut score is developed to maintain a predetermined level of ongoing knowledge for the BoK field of experience (this is not just a simple 70 percent or some other numerical pass score). H1493 Ramu_p00i-284.indd 22 7/13/16 5:55 PM The ASQ Certification Process xxiii • With the cut score established for a given exam sequence, all exams are then reviewed to determine those who passed. Any examinee that falls below the cut score will receive a Pareto diagram of their exam identifying where they had problems. Those that pass the exam will receive a certification and exam card for their wallet or purse. • Once an exam has been given, the exam questions are statistically reviewed for how well they discerned the knowledge of the applicants. Any questions that were generally missed or passed by a significant portion of the audience will be discarded. Only a very few of the questions will return to the exam bank for possible use on a future exam. • Every five years this cycle is repeated for each exam that ASQ offers. This process is long and tedious, and ASQ spends a lot of time, resources, and volunteer effort to maintain this process to ensure the highest level of professionalism possible for the certifications offered by the Society. Once you pass an exam, you are encouraged to join in this process to help ensure that future exams will be meaningful to the participants. Ongoing Maintenance As can be seen in the previous section, ASQ maintains a comprehensive process for ensuring that exams are reviewed every five years and that the exams are of the highest professionalism possible. To this end, security is tight for the entire process, and very few individuals know the entire history of an exam question's life to ensure that questions are not released to exam participants prior to an exam being given. Some of the general activities that ASQ uses to maintain exam processes are: • If you are a local section volunteer helping to administer a refresher program or teach a refresher course or other training process, you are not allowed to proctor an exam for the same BoK. • If you proctor an exam for a section or conference, you are not allowed to teach that BoK. • If you volunteer to assist with any of the activities listed in the previous section on the exam development cycle, you are not allowed to teach or publish anything related to that BoK. • ASQ maintains an ASQ National Certification Committee for each exam that is offered through the Society. Each exam is either coordinated through an ASQ division (based on their field of expertise) and/or the ASQ National Headquarters, who coordinates with all ASQ divisions that might have a stake in a specific exam. • These ASQ National Certification Committees are made up of ASQ member volunteers who meet on a regular basis to ensure that the processes listed above, the ASQ national activities, and other issues related to their specific exam are maintained at the highest possible H1493 Ramu_p00i-284.indd 23 7/13/16 5:55 PM xxiv Introduction level of professionalism. This includes recertification activities for those exams that have that requirement. • These ASQ National Certification Committees ensure that the process listed in the previous section is followed (usually by participating in and/or coordinating the various events) as well as ensure that the BoK is positioned for reevaluation every five years. After the questions have been used for a certain period of time, they will be put into an archival file with notes on each as to when it was used and statistical results of how the question performed on the exam. These old files can occasionally be used as a basis for writing new or variations of questions. Thus, it would be unlikely to see one of these questions show up on a future exam. While using practice exams (as included on the CD-ROM accompanying this handbook) for study can be useful, the user should realize that these are not the same questions that will be on the ASQ exam. The Examination Process Given the aforementioned process, the ASQ exam candidate should realize that anyone saying that they have inside information as to what will be on any given exam is either violating the ASQ Code of Ethics (by stealing information, in which case ASQ will prosecute if found out) or stretching the truth in the way that they are presenting the information. The ASQ certification exam process is always evolving and will rarely ever have a question in the same format on any two given exams. The candidate must be prepared to answer questions that could be reasonably extracted from the ASQ Certified Six Sigma Yellow Belt BoK (see Appendix B). Also, given the number of various industries in the marketplace today, general questions can be asked about a given topic in any number of ways. One example, FMEA (note: acronyms are very rarely used in the actual exam). If you are in the automotive industry you might use the AIAG Potential Failure Mode and Effects Analysis (FMEA) Reference Manual, 4th edition (products-list/product-details?ProductCode=FMEA-4) or the SAE J1739:2009 standard (. On the other hand, if you are in the medical devices industry, you would have to use BS EN ISO 14971:2007 Medical devices—Application of risk management to medical devices (. com/ProductDetail/?pid=000000000030091423). Still other industries might use the book Failure Mode Effect Analysis: FMEA from Theory to Execution, Second Edition. Either way, any question related to FMEA might focus on what the primary function of FMEA is, which is to manage the risk of the product or service that your organization offers to a customer (either internal or external). So, you should not be shaken if a question sounds as if it comes from an industry other than the one in which you work. The point is whether you can decipher the intent of the question as it relates to the Yellow Belt BoK and answer the question using facts and reason. The sample questions on the CD-ROM have been selected from sample exam questions from ASQ Certification pages for you to use for practice. An effort was made to ensure that only the sample questions relevant to the CSSYB BoK were selected. H1493 Ramu_p00i-284.indd 24 7/13/16 5:55 PM The ASQ Certification Process xxv The ASQ Certified Six Sigma Yellow Belt Guidelines booklet starts off the explanation of the BoK with: Included in this body of knowledge (BoK) are explanations (subtext) and cognitive levels for each topic or subtopic in the test. These details will be used by the Examination Development Committee as guidelines for writing test questions and are designed to help candidates prepare for the exam by identifying specific content within each topic that can be tested. Except where specified, the subtext is not intended to limit the subject or be all-inclusive of what might be covered in an exam but is intended to clarify how topics are related to the role of the Certified Six Sigma Yellow Belt (CSSYB). The descriptor in parentheses at the end of each subtext entry refers to the highest cognitive level at which the topic will be tested. A complete description of cognitive levels is provided at the end of this document. After the BoK is listed, a description of the meanings of remember, understand, apply, analyze, evaluate, and create is given. This is important as it tells you the examinee what level of knowledge you will need for that category of the BoK. The ASQ booklet lists the levels of cognition as: Based on Bloom's Taxonomy—Revised (2001) In addition to content specifics, the subtext for each topic in this BoK also indicates the intended complexity level of the test questions for that topic. These levels are based on "Levels of Cognition" and are presented below in rank order, from least complex to most complex. Remember (Knowledge Level) Recall or recognize terms, definitions, facts, ideas, materials, patterns, sequences, methods, principles, and so on. Understand (Comprehension Level) Read and understand descriptions, communications, reports, tables, diagrams, directions, regulations, and so on. Apply (Application Level) Know when and how to use ideas, procedures, methods, formulas, principles, theories, and so on. Analyze (Analysis Level) Break down information into its constituent parts and recognize their relationship to one another and how they are organized; identify sublevel factors or salient data from a complex scenario. Evaluate (Evaluation Level) Make judgments about the value of proposed ideas, solutions, and so on, by comparing the proposal to specific criteria or standards. Create (Synthesis Level) Put parts or elements together in such a way as to reveal a pattern or structure not clearly there before; identify which data or information from a complex set are appropriate to examine further or from which supported conclusions can be drawn. H1493 Ramu_p00i-284.indd 25 7/13/16 5:55 PM xxvi Introduction These words can be kept in mind while reviewing the chapters in this book to get a better sense of the detail of questions that could be asked in that section. This is also why it may appear that some material is covered in more than one section of the BoK. In preparing for the actual exam, we suggest that you do the following: • Follow the list of "What Can and Can Not Be Brought into the Exam Site" found on the ASQ certification website—Frequently Asked Questions—"Taking the Exam." • Select the reference that you have used in preparing for the exam. You should be familiar with how the reference is laid out and how you will use it. • Create an index of your planned references—you are allowed to use self-prepared information as long as there are no practice exam questions in the material. • Consider having a good Standard English dictionary available. Sometimes a word might be used in the questions that you may not be familiar with. • Arrive at the exam site early so that you can set up your materials in a manner that best fits your needs. You might even call the chief proctor ahead of time to learn the room layout if you have not been to the particular exam site before. • Remember that anything that you write on during the exam (scratch paper, exam pages, answer sheets, and so on) must be turned in to the proctor at the end of the exam. Thus, during the exam do not write in any of your references that you want to take home with you. • Relax and breathe. Additional advice given in the ASQ Certified Six Sigma Yellow Belt brochure includes: Test takers are also advised to keep in mind these general pointers about standardized exams: • Read all of the questions on the first page of the test so you realize that you do know the material. In other words, relax. • Read each question thoroughly. Don't assume you know what's being asked. • Eliminate implausible answers and move quickly past the obviously wrong choices. • Keep in mind that an answer may be a correct statement in itself but may not answer the question. • Two answers may say exactly the opposite things or may be very similar. Read them again to decide what makes one correct and the other wrong. • ASQ does not subtract points for incorrect answers. Answer every question. There is no penalty for guessing, so you have a minimum 25 percent chance H1493 Ramu_p00i-284.indd 26 7/13/16 5:55 PM The ASQ Certification Process xxvii of getting it right, and even higher if you are successful in eliminating one or two of the answers as incorrect. • Go through and answer the questions you know. Then go through and read the ones you're unsure of. • Mark those you are still uncomfortable with. You will narrow the field down to just a few questions you will need to spend more time on. These are the questions you might want to use your reference books for. • Be aware of the time available for the exam and the remaining time as you work through the exam. • Do not select more than one answer for a question. If you do, it will be scored as a "blank." For example, you think that both A and C are correct answers. Select only one answer and use the comment sheet supplied with your test to point out why you think both A and C are correct. Your comments will be reviewed before results are reported. Taking an exam (offered by ASQ or any other organization) is a matter of preparation on the participant's part, and your results will show how well you achieved the exam requirements. We have seen people who based on overall education should pass an exam not do well, and the other extreme where a person who we thought might struggle but studied very hard actually passed the exam. Study and use your reference materials, and know where and how to find information when you need it. Few people can memorize everything, so the next best thing is knowing how to find information quickly when needed so that you can finish the exam in a timely manner. The breadth and scope of material within this handbook is based on the current version of the ASQ BoK for Certified Six Sigma Yellow Belt practitioners. When reviewing the material, there are two considerations: c overage and intensity. Coverage reflects the material in relation to the expected scope of the exam. ASQ has defined for each BoK category the number of questions expected to be present on the exam. It is important to devote the appropriate time to each s ection in order to ensure proper preparation. Without considering the coverage of the BoK, there is a risk that certain portions will be inadequately addressed in advance of the exam. One practice is to create a matrix on a spreadsheet indicating the BoK items on one axis, and the study progress made for each item on the other. Maintaining such a matrix would clearly indicate those areas where mastery has been achieved, and where more effort is required. Intensity refers to the learning level specified by ASQ, as referenced by the Bloom's Taxonomy category. Those topic areas with the highest knowledge levels require additional effort by the examinee to fully master the concepts to sufficiently select or derive the correct response on the exam. Consequently, more effort should be devoted to those BoK items with the highest levels of knowledge, as these will align with the most complicated and time-consuming questions on the exam. For convenience, those items with the highest levels have been included within the following table for extra attention. H1493 Ramu_p00i-284.indd 27 7/13/16 5:55 PM xxviii Introduction The components of the BoK are explained below with two examples. In the Yellow Belt BoK, only two levels of cognition are used: "Understand" and "Apply." Section Subsection Knowledge area Knowledge item I. Six Sigma Fundamentals D. Team basics 1. Types of teams Identify the various types of teams that operate within an organization (i.e., continuous improvement, self-managed, and cross-functional) and their value. (Understand) II. Define Phase A. Project identification 4. Process inputs and outputs Use SIPOC (suppliers, inputs, process, outputs, customers) to identify and define important elements of a process. (Apply) Additional guidance for planning for, preparing for, and taking any ASQ Certification exam is available in Quality Progress (2010/01/certification-asq/test-run.html). Exam takers are encouraged to read this publication prior to planning to take an ASQ Certification exam. H1493 Ramu_p00i-284.indd 28 7/13/16 5:55 PM Preface W elcome to The Certified Six Sigma Yellow Belt Handbook. This reference manual is designed to help both those interested in passing the certification exam of the American Society for Quality (ASQ) for the Six Sigma Yellow Belt and those who want a handy reference to the appropriate materials needed for successful Six Sigma projects. I have made a sincere attempt to make this book a reference for both beginners in Six Sigma and those who are already knowledgeable about process improvement and variation reduction. The primary layout of the handbook follows ASQ's Body of Knowledge (BoK) for the Certified Six Sigma Yellow Belt (CSSYB) released in 2015. I have utilized feedback from Six Sigma practitioners and knowledge gained through helping others prepare for exams to create a handbook that I hope will be beneficial to anyone seeking to pass the ASQ CSSYB or other Six Sigma exams. In addition to the primary text, the handbook contains numerous appendixes, a comprehensive list of abbreviations, and practice exam questions; a CD-ROM accompanying the book contains additional materials. One caution—you are not allowed to take any of the exam questions from the CD-ROM or from any other simulation into the ASQ exam. While most ASQ certification exams use solely a multiple-choice question format (ASQ CMQOE and CSSMBB are exceptions), many users of ASQ handbooks on the academic side prefer essay-type questions for the chapters to test the comprehension of students using this book at colleges and universities. I would advise the ASQ exam takers to make a note of this but not be too concerned. The essay questions were added to challenge the users. The difficulty level of the essay questions is likely higher than that of the questions in the ASQ certification exam. Six Sigma trainers for organizations may find this additional feature useful, as they want their trainees (staff) to not only pass ASQ Six Sigma exams but have a comprehensive understanding of the Body of Knowledge that will allow them to support real Six Sigma projects in their roles. I intend to start an ASQ CSSYB handbook users group in LinkedIn (a w eb-based social media application for professionals) and would greatly appreciate readers' comments and feedback on how the handbook can be improved. Constructive and respectful posts are encouraged. Users will be acknowledged if their input and feedback are found useful and incorporated into the next edition. I encourage users of the handbook to read the ASQ Quality Progress publication "Test Run" to obtain tips for passing the ASQ exam (and also located on this book's CD-ROM). xvii H1493 Ramu_p00i-284.indd 17 7/19/16 5:02 PM xviii Preface Test-takers will also find useful the CSSYB keyword search located on the CD-ROM. This lists the terms and phrases in the BoK and where they are located within the handbook, since in an open-book exam it is useful to the test-taker to be able to quickly find these within the book. It is recommended you print this out to use in conjunction with the handbook during the exam. Where Are You in Your Career? Over the course of your professional career, you have learned to use many tools. Certification as a Six Sigma Yellow Belt is the beginning of your journey of achieving higher levels of accomplishments and potentially lifelong learning. Consider this as laying the foundation. The following career pyramid provides guidance on reaching additional certifications. It is not a representation of ASQ certification exam requirements or prerequisites; rather, it presents a logical order of how one would progress. Level of accomplishment based on author's assessment ASQ's CMQ/OE, CSSMBB ASQ's CQA, CHA, CBA, CSSBB, CPGP, CSQP, CQE, CRE, CSQE ASQ's CSSGB, CCT, CQT ASQ's CSSYB, CQI, CQPA, CQIA Best wishes as you embark on your Six Sigma journey! H1493 Ramu_p00i-284.indd 18 7/19/16 5:35 PM Table of Contents List of Figures and Tables. . . . . CD-ROM Contents . . . . Preface. . . . . Acknowledgments. . . . . Introduction: The ASQ Certification Process. . . . . xi xv xvii xix xxi Part I Six Sigma Fundamentals. . . . . 1 Chapter 1 A. Six Sigma Foundations and Principles . . . . Purpose of Six Sigma: Reducing Variation . . . . Methodology (DMAIC) . . . . Evolution of Six Sigma from Quality. . . . . Value of Six Sigma to the Organization as a Whole. . . . . 2 2 4 7 9 Chapter 2 B. Lean Foundations and Principles . . . . Purpose of Lean. . . . . Lean Methodologies . . . . Value of Lean to the Organization. . . . . 13 13 17 23 Chapter 3 C. Six Sigma Roles and Responsibilities. . . . . 28 Chapter 4 D. 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Kaizen and Kaizen Blitz. . . . . 2. Plan-Do-Check-Act (PDCA) Cycle. . . . . 3. Cost-Benefit Analysis . . . . 158 158 160 163 Chapter 17 B. Control Tools and Documentation . . . . 1. Control Plan. . . . . 2. Control Charts. . . . . 3. Document Control. . . . . 168 168 173 178 H1493 Ramu_p00i-284.indd 8 7/13/16 5:55 PM Table of Contents ix Part VI Appendices. . . . . 183 Appendix A ASQ Code of Ethics . . . . 184 Appendix B ASQ Certified Six Sigma Yellow Belt (CSSYB) Body of Knowledge (2014). . . . . 186 Appendix C ASQ BoK Comparison. . . . . 191 Appendix D Control Limit Formulas. . . . . 195 Appendix E Constants for Control Charts . . . . 196 Appendix F Areas under Standard Normal Curve . . . . 197 Appendix G Binomial Distribution. . . . . 201 Appendix H Values of the t-Distribution. . . . . 203 Appendix I Acronym List. . . . . 205 Glossary . . . . Notes. . . . . Bibliography. . . . . Index. . . . . H1493 Ramu_p00i-284.indd 9 235 263 267 269 7/13/16 5:55 PM Part I Six Sigma Fundamentals Chapter 1 Chapter 2 Chapter 3 Chapter 4 Chapter 5 A. Six Sigma Foundations and Principles B. Lean Foundations and Principles C. Six Sigma Roles and Responsibilities D. Team Basics E. Quality Tools and Six Sigma Metrics 1 H1493 Ramu_p00i-284.indd 1 7/13/16 5:55 PM Chapter 1 A. Six Sigma Foundations and Principles Describe the purpose of six sigma (reducing variation), its methodology (DMAIC) and its evolution from quality. Describe the value of six sigma to the organization as a whole. (Understand) Body of Knowledge I.A Purpose of Six Sigma: Reducing Variation The main purpose of a f or-profit organization is to generate money for operating the business and making profits for shareholders. Even the organization that is not for profit (e.g., American Society for Quality [ASQ]) has to generate enough money to cover operational costs and to fund future programs that bring value to customers (i.e., ASQ members). These organizations generate income by offering products and services to customers. There is no guarantee that every product and service delivered to customers will be identical. There is some variability that is inherent to products and services. What if the variability increases to an extent that it affects the customer? Let's look at some different scenarios. If you purchase a gallon of gas and the gas pump dispenses anywhere from three-fourths of a gallon to one gallon, would you find that acceptable? If a healthcare clinic delivers between 0.25 mL and 1 mL of the flu vaccine against the specification of 0.5 mL ± 0.05 mL, would you still get a flu shot from this clinic? While variability is inherent, organizations strive to keep it as low as possible in order to deliver products and services that meet or exceed customer expectations. Highly variable products and services result in poor quality, and the organization must spend money to correct the defect. If an organization spends more than it takes in, it will be out of business. Thus, the challenge for every organization is to become profitable at whatever it does so that it can continue to do what it does. Managers, employees, suppliers, and customers all have their wants and needs that the business must satisfy in an effective and efficient manner so profit can be achieved. Six Sigma as a disciplined methodology for improvement and problem solving helps achieve just that with a focus on the bottom line. Six Sigma is a structured and disciplined process designed to consistently deliver perfect products and services. It aims to improve the bottom line by finding 2 1 H1493 Ramu_p00i-284.indd 2 7/13/16 5:55 PM Chapter 1 A. Six Sigma Foundations and Principles 3 and eliminating the causes of mistakes and defects in business processes. Sigma (σ) is a statistical term that refers to the standard deviation of a process about its mean. A wide range of companies have found that when the Six Sigma philosophy is fully embraced, the enterprise thrives. What is this Six Sigma philosophy? Several definitions have been proposed. Common threads of these definitions are the following: • Use of teams that are assigned to well-defined projects that have direct impact on the organization's bottom line. • Training in statistical thinking at all levels of the organization and providing key people with extensive training in advanced statistics and project management. These key people are designated Black Belts and Master Black Belts. • Emphasis on the DMAIC approach to problem solving: define, measure, analyze, improve, and control. • A management environment that supports these initiatives as a business strategy. Opinions on the definition of Six Sigma differ: • Philosophy. The philosophical perspective views all work as processes that can be defined, measured, analyzed, improved, and controlled. Processes require inputs [illegible] be expected to use the tools in this book, and possibly tools in other books, to study your work and processes for improvement ideas and to implement those ideas. You may already be familiar with some of these tools, and the challenge will be how to use them, possibly in new ways, to make changes that will help your company stay in business in today's fiercely competitive world. We no longer compete against others within just our own country, but against others from countries around the world. How can we compete with our competitors in other countries that can manufacture product or provide service faster, better, and at a lower cost than we can? This is the question that should be on your team's mind. Ishikawa gave us a road map to follow when first looking at a process that needs to be improved. The words may not make much sense right now, but as you work with process improvement, you will come to understand the importance of what is said here: 1. Determine the assurance unit (what is to be measured) 2. Determine the measuring method (how it will be measured) 3. Determine the relative importance of quality characteristics (is this key to our process?) 4. Arrive at a consensus on defects and flaws (does everyone agree on good and bad quality?) 5. Expose latent defects (look at the process over time) 6. Observe quality statistically (use process behavior charting) 7. Distinguish between "quality of design" and "quality of conformance" After we know what we can change (quality of conformance) and what we cannot change right now (quality of design—this is left to Design for Six Sigma [DFSS]), we can start working on our processes. Some operators initially view this effort as only more work, but find that doing these studies actually saves them a lot of time and grief in the future as things start to improve and machines start to work better. Questions to ask yourself now are, How often does your process slow down or stop due to something not working the way it should? and Is the output ever scrapped by someone down the line (including at your external customers) because something was missed or processed incorrectly at your operation? Be willing to experiment with the tools and look for ways of applying them to the work and processes to learn as much as you can about how a process operates. This will allow you to modify it as appropriate and give the customer the best possible output. H1493 Ramu_p00i-284.indd 11 7/13/16 5:55 PM 12 Part I Six Sigma Fundamentals The Six Sigma Road Map As we prepare for the Six Sigma journey, here is a quick view of the suggested map we should follow: 1. Recognize that variation exists in everything that we do; standardize your work. 2. Identify what the customer wants and needs. Reduce variation. 3. Use a problem-solving methodology to plan improvements. 4. Follow the DMAIC model to deploy the improvement. 5. Monitor the process using process behavior charts. 6. Update standard operating procedures and lessons learned. 7. Celebrate successes. 8. Start over for continual improvement. Questions 1. Structured problem solving and continual improvement approaches like PDCA have been around since the 1950s. The 1980s and 1990s saw the introduction of many new approaches and methodologies like TQM and business process reengineering. How did an improvement methodology like Six Sigma become the mantra of management and the most widely accepted methodology by organizations? 2. Research the common criticisms of Six Sigma and prepare your position. You may support the criticisms or counterargue with your viewpoint. Ask your audience to weigh in. H1493 Ramu_p00i-284.indd 12 7/13/16 5:55 PM Chapter 2 B. Lean Foundations and Principles Describe the purpose of lean (waste elimination) and its methodologies (just-in-time, p oka-yoke, kanban, value-stream mapping). Describe the value of lean to the organization as a whole. (Understand) Body of Knowledge I.B Purpose of Lean The purpose of lean is to reduce waste in the value stream and provide maximum value to our customers; that is, do more with less. Over the years we have adopted many industry practices that emphasize maximizing output from our investment (like machinery) or from the people we employ. We have not considered whether such outputs are required by our customers at the level of quality and in the quantity they want. We have produced goods that piled up in inventories. Production managers were rewarded for overproduction. Sales managers were pressured to sell the inventories. Gullible customers fell for the marketing ploy and purchased the product only to realize that it was not what they wanted. We ended up with a society that oversupplied products that were undervalued by consumers. There were no winners. Lean concepts address all these weaknesses in the traditional business model and industry practices and provide methodologies that will bring the utmost value to our customers and ensure the organization is economically sustainable. Value Stream A value stream is the series of activities that an organization performs, such as order, design, produce, and deliver products and services. A value stream often starts from a supplier's supplier and ends at the customer's customer. Wastes are both explicit and hidden along a value stream. 13 2 H1493 Ramu_p00i-284.indd 13 7/13/16 5:55 PM 14 Part I Six Sigma Fundamentals There are three main components of a value stream: 1. The flow of materials from receipt of supplier material to delivery of finished goods and services to customers. Examples: — Raw material shipped weekly (or at periodic intervals) from supplier to the organization by truck — Movement of material from raw material storage to production process through to finished goods warehouse — Shipping of the finished goods to overseas customer via customs 2. The transformation of raw materials into finished goods, or inputs into outputs. Example: — Production steps like cutting, shaping, forging, welding, polishing, and assembly 3. The flow of information required to support the flow of materials and transformation of goods and services. Example: — Purchase order to supplier, internal work order, shipping notice This concept is visually illustrated with a lean tool called the value stream map. This map uses simple graphics and icons to illustrate the movement of material, information, inventory, work- in-progress, operators, and so on. Value stream mapping is a simple yet powerful tool. The analysis subsequent to value stream mapping—value stream analysis—can help uncover hidden wastes within the organization. An organization that effectively uses lean thinking and applies lean tools to reduce waste throughout the value stream and offer value to its customers is a lean enterprise organization. Becoming a lean enterprise requires a change in people's attitudes, procedures, processes, and systems. It is necessary to zoom out and look at the flow of information, knowledge, and material throughout the organization. In any organization there are multiple paths through which products, documents, and ideas flow. The process of applying lean thinking to such a path can be divided into the following steps: 1. Walk the process. Go to the gemba (workplace) and produce a value stream map. This is also referred to as a value chain diagram. It has boxes labeled with each step in the process. Information about timing and inventory is provided next to each process box. Figure 2.1 shows some of the symbols used in value stream maps. Figure 2.2 shows an example of a value stream map. 2. Analyze all inventory notes with an eye toward reduction or elimination. Inventory tends to increase costs because: — Storage space may be expensive (rubber awaiting use in a tire factory is stored at 120°F; wood inventory may need to be humidity-controlled). — Quality may deteriorate (rust, spoilage, etc.). H1493 Ramu_p00i-284.indd 14 7/13/16 5:55 PM Chapter 2 B. Lean Foundations and Principles Process box Production kanban OXOX Withdrawal kanban Batch kanban Information flow Batch withdrawal Electronic data Kanban post Transport arrow Withdrawal or physical pull Load leveling (heijunka box) Supermarket Customer/ supplier Push arrow 15 Safety/Buffer stock FIFO lane FIFO Pull arrow Kaizen idea Inventory Signal kanban Shipment truck "Go and see" trigger Figure 2.1 Common symbols used in value stream mapping. — Design changes may be delayed as they work their way through the inventory. — Money sitting in inventory could be used more productively elsewhere (locked cash). — Quality problems that are not detected until a later stage in the process will be more expensive to correct if an inventory of defective products has accumulated. 3. Analyze the entire value stream for wasteful steps. These steps are called non-value-added activities and are discussed in detail later in this chapter. 4. Determine how the flow is driven. Strive to move toward value streams in which production decisions are based on the pull of customer demand. In a process where pull-based flow has reached perfection, H1493 Ramu_p00i-284.indd 15 7/13/16 5:55 PM 16 H1493 Ramu_p00i-284.indd 16 3- c fore Sal es f ore We ek ates upd ly Wee Supplier Customer service ly o Shi Weekly schedule r fo In ppi n io at m 40K cases Customer sch edu le 1× daily s da ta h y sc r bo x le edu ng t rde C/O (mins) Shifts 13 3 Uptime (%) ry C/O (mins) 8 Shifts 1 Uptime (%) 60 CT (sec) 90 Inventory (hrs) CT (sec) 33 Shipping C/O (mins) 3 C/O (mins) Shifts 1 Shifts Uptime (%) 72 75 Inventory (hrs) CT (sec) 0.5 74 46 40 1 Uptime (%) 63 Inventory (hrs) CT (sec) 28.8 85 me Lead ti Total lead Pr oc es si ng tim e Inventory (hrs) 120 Neck bender (W Cleaner to Inspector In ve n Tuesday and Thursday IP) Pr oc es iver Del cas Total processing Figure 2.2 Value stream map example. Part I Six Sigma Fundamentals th mon Production control Purchasing ast 7/13/16 5:55 PM Chapter 2 B. Lean Foundations and Principles 17 a customer order for an item will trigger the production of all the component parts for that item. 5. Extend the value stream map upstream into suppliers' plants. When beginning the process, identify a manageable scope with boundaries. The flows of information, material, knowledge, and money are all potential targets for lean improvements. Lean Methodologies 5S 5S is a workplace organization method that can help improve the efficiency and management of operations (see Figure 2.3). 5S is the simplest and most practical improvement that an individual or organization can start with. It requires few or no resources, yet the payback can be impressive from the day of implementation. A [illegible]

factor that has helped Six Sigma be successful is the structure it demands of organizations. Table 3.1 shows typical Six Sigma roles, the organizational members that typically fill the roles, their expected training or background, and the primary responsibilities of each role. Organizations may employ program managers to assist the Master Black Belts in managing the overall Six Sigma implementation across the organization. The organization's finance department may also play a role by verifying the benefits claimed by the projects before the projects are presented to management. Questions 1. You have been assigned to set up a Six Sigma organization for a company with fewer than 100 employees. Understanding that not every organization can afford a structure as identified in Figure 3.1, how would you structure your Six Sigma resources? What roles would you have? What will be their responsibilities? 28 3 H1493 Ramu_p00i-284.indd 28 7/13/16 5:55 PM Chapter 3 C. Six Sigma Roles and Responsibilities 29 VP quality, business unit leader Executive sponsor(s) Master Black Belt(s) Champion Champion Champion Process owner Process owner Process owner Process owner Process owner Process owner Black Belt Green Belt Team members and Yellow Belt(s) Figure 3.1 Typical large Six Sigma organization. 2. How do you ensure the continuity of the Six Sigma organization? Make recommendations. 3. What are the challenges of sustaining Six Sigma improvement projects without Six Sigma resources? H1493 Ramu_p00i-284.indd 29 7/13/16 5:55 PM 30 H1493 Ramu_p00i-284.indd 30 Role Candidate Training/background Primary responsibilities Executive sponsor Business unit leader responsible for profit and loss (usually at director level or above) Six Sigma concepts, strategies, • Set direction and priorities for the Six Sigma organization overview, operational definitions. • Allocate resources for projects • Set Six Sigma vision and overall objectives for the program • Monitor the progress of the overall program • Initiate incentive programs • Reward successful projects Champion Typically upper-level managers Six Sigma concepts, strategies, tools and methods, operational definitions. Emphasis on management tools. (ASQ Certified Six Sigma Yellow Belt) Process owner An individual responsible and accountable for the execution and results of a given process. The sponsor or champion could also be a process owner. Six Sigma concepts, strategies, tools and methods, operational definitions. Emphasis on statistical tools. (ASQ Certified Six Sigma Yellow Belt) • Liaise with senior management • Allocate resources for projects • Determine project selection criteria • Remove barriers hindering the success of the project • Approve completed projects • Implement change • Select team members • Allocate resources for projects • Provide process knowledge • Review process changes • Approve changes/ support change management • Implement change • Ensure that improvements are sustained Part I Six Sigma Fundamentals Table 3.1 Typical Six Sigma roles. (Continued) 7/13/16 5:55 PM Role Master Black Belt Black Belt Candidate Training/background Primary responsibilities Individuals trained in Six Sigma methodologies, statistical tools, basic financial tools, change management, risk assessment, project management, executive communication, and well experienced in teaching, coaching, and mentoring Black Belts and Green Belts. This is always a full-time position. Six Sigma BoK, lean enterprise synergy, finance for nonfinancial managers, risk assessment, project management, change agent skills, Master Black Belt train the trainer, presentation skills, communication skills, leadership skills, facilitation skills. • Coach Six Sigma Black Belts and Green Belts • Utilize the resources provided by management effectively • Formulate overall business strategy linking to Six Sigma program • Monitor project progress closely • Typically 15–20 projects overseen at a time • Provide coaching, mentoring for new Black Belts and Green Belts • Work with champions and process owners for selection of projects • Address issues of project stagnation • Remove barriers hindering the success of the project • Support as a subject matter expert for the organization • Review and approve completed projects • Share lessons learned with the extended team • Provide inputs to rewards committee Individuals trained in Six Sigma methodologies, statistical tools, basic financial tools, change management, risk assessment, project management, and well experienced in managing Black Belt projects. This is always a full-time position. Six Sigma Black Belt Body of Knowledge, lean enterprise synergy, finance for nonfinancial managers, risk assessment, project management, change agent skills, presentation skills, communication skills, leadership and facilitation skills. (ASQ Certified Six Sigma Master Black belt) (ASQ Certified as Six Sigma Black Belt) 7/13/16 5:55 PM (continued) 31 • Lead and manage Six Sigma projects • Utilize the resources provided by management effectively • Provide net present value, return on investment (ROI), payback calculations on projects • Work full-time on four to six projects per year • Monitor project progress closely • Follow DMAIC process, apply appropriate statistical methods • Work with champions, Master Black Belts, and process owners for selection of projects • Address issues of project stagnation/consult Master Black Belt • Remove barriers hindering the success of the project • Update and present project progress to management • Review completed projects • Share lessons learned with the extended team Chapter 3 C. Six Sigma Roles and Responsibilities H1493 Ramu_p00i-284.indd 31 Table 3.1 Typical Six Sigma roles. (Continued) Candidate Green Belt Individuals trained in Six Sigma methodologies, basic statistical tools, and process improvement techniques. This is typically a fulltime position. However, some organizations make this part of an existing job responsibility. Six Sigma Green Belt BoK, lean enterprise synergy, presentation skills, communication skills. Individuals trained to have awareness in Six Sigma methodologies, and understanding of basic statistical tools, and process improvement techniques. This is not a fulltime position. Organizations make this part of an existing job responsibility. Management and Champion are also trained in yellow belt. Six Sigma methodologies, principles, value, quality tools, process improvement, and teamwork. Selected by process owner and trained in Six Sigma methodologies, quality, basic statistical tools, and process improvement techniques. Six Sigma methodologies, quality • Support and contribute to Six Sigma projects • Participate in charter and scope definition tools, process improvement, • Provide inputs during project meeting, brainstorm ideas teamwork. • Help collect data where responsible • Follow DMAIC process, apply appropriate tools • Review the approach periodically with the Green Belt and experienced Black Belt • Provide inputs to Green Belt and Black Belt and process owners during project Yellow Belt Project team member Training/background (ASQ Certified as Six Sigma Green Belt) (ASQ Certified Six Sigma Yellow Belt) Primary responsibilities • Support Six Sigma projects with higher ROI • Lead smaller projects with moderate savings and ROI • Follow DMAIC process, apply appropriate statistical methods • Review the approach periodically with the experienced Black Belt and Master Black Belt • Provide inputs to Master Black Belt and Black Belt and process owners during selection of projects • Identify issues of project stagnation/consult Black Belt, Master Black Belt • Identify and report barriers hindering the success of the project • Share lessons learned with the extended team • Support and contribute to Six Sigma projects • Provide inputs during project meeting, brainstorm ideas • Help collect data where responsible • Follow DMAIC process, apply appropriate tools • Review the approach periodically with the Green Belt and experienced Black Belt • Yellow belts may be at a contributor to a project or a champion of a project Part I Six Sigma Fundamentals 7/13/16 5:55 PM Role 32 H1493 Ramu_p00i-284.indd 32 Table 3.1 Typical Six Sigma roles. (Continued) Chapter 4 D. Team Basics Identify the various types of teams that operate within an organization (i.e., continuous improvement, self-managed and cross-functional) and their value. (Understand) Body of Knowledge I.D.1 1. Types of Teams You are probably familiar with the saying "There is no 'I' in 'team.'" The essence of it is to imply that a team is a collective effort of individuals. To harness the best of each individual, the team members need to understand each other's strengths, roles, and responsibilities and the scope of the task. There are several books that go into detail about how to form a team, organize meetings, manage projects, and accomplish the desired goals. In the context of Six Sigma, we will cover areas important to a Six Sigma Yellow Belt. Protocols such as setting the team agenda, recording the minutes of the meeting with actions, sticking to meeting times, and enforcing meeting attendance need to be followed for an effective team meeting. An initial meeting to kick off the team with introductions and a high-level discussion of the goal, objective, milestones, and so on, will provide an opportunity for the team members to get to know each other and understand the expectations. A team must have an agenda, but it can be flexible. Some teams have their team goals, objective, and scope/boundaries visibly displayed in every meeting to keep the members on track. Management presence during kickoff and frequently during the project helps enforce the importance of the team objective. Team Formation A team usually comprises five to seven members with complementary skills to achieve the goals and objectives of the team. Team composition should be driven by the size and scope of the project; it is possible to have a team of two or three individuals for a smaller project and a large team with subteams for a bigger project. The team includes subject matter experts and stakeholders. Subject matter 33 4 H1493 Ramu_p00i-284.indd 33 7/13/16 5:55 PM 34 Part I Six Sigma Fundamentals experts sometimes remain outside the team as resources or extended team members. Stakeholders are always part of the team. The team will not be able to implement its ideas and solutions without having stakeholders or their representation on the team. Teams smaller than five individuals are easier to manage than larger teams, but the opportunity for interaction and ideas is reduced. Teams larger than seven individuals produce a lot of interaction that can be counterproductive to a team's progress. Teams with greater diversity tend to produce better interactions between team members. In some cases, teams bring in individuals who are neither subject matter experts nor stakeholders but outsiders. The outsider helps the team ask questions that were never explored by the team members closest to the process. However, the use of outsiders needs to be moderated, as the outsider might ask too many questions and frustrate the core members by slowing down the progress. Typically, cross-functional Six Sigma teams are formed to address the issues from every angle. Virtual Teams Virtual teams are an interesting evolution in the past decade due to the development of technology in communication tools and the Internet, which have led to the ability to meet and share data virtually. Virtual teams enable people from all over the globe to meet via teleconferences, videoconferences, and Internet tools such as shared computers. The virtual team has many benefits, the most prevalent being reduced administrative and logistical costs and r eal-time data sharing and updating. However, virtual teams also face challenges that include slowing of the progression of normal team-building, inability to get true commitment and buy-in, and the potential for miscommunication—especially with teleconferencing, as the important factor of nonverbal communication is lost. Additionally, technology-related issues can cause distraction and reduce the effectiveness of the meeting. Virtual teaming has its place in every organization and can be very effective, especially if team members are familiar with each other. Hence, it may be beneficial for the team to meet face to face at some period during the project. This relationship can be helpful to project continuity. Continuous Improvement Teams Team members are often from the same process with varying responsibilities. The team is given a clear goal by management to improve yield, productivity, safety, and so forth. The team appoints a leader (process owner), meets regularly, applies continual improvement tools, and reaches the goal. Once the goal is achieved, the team goes to work on the next goal. Self-Managed Teams A self-managed team is a group of independent team members who plan, direct themselves, and operate with a set of procedures toward a common goal. Team harmony is achieved after the team members have worked with each other on other projects and have appreciation for each other's skill and disposition. Projects and purpose are carefully chosen for self-managed teams. The team members have proven effectiveness. H1493 Ramu_p00i-284.indd 34 7/13/16 5:55 PM Chapter 4 D. Team Basics 35 Cross-Functional Teams Product development, continual improvement, and problem- solving projects require a cross-functional team to be assembled. Representatives from all the different functions will be required in order to obtain the knowledge and experience needed for a project. Cross-functional team members will be needed in order to implement any solution the team comes up with. Cross-functional teams have several advantages in terms of efficiency and results, but they also have challenges. Priorities for cross-functional members may be different. They may not feel the same sense of urgency and provide the same level of commitment as a team whose members are from one business function. The team leader, with management support from the sponsor of the project, should set the tone for the common purpose. Describe the various stages of team evolution: forming, storming, norming, performing, and adjourning. (Understand) Body of Knowledge I.D.2 2. Stages of Development Team Stages and Dynamics It is important to understand team dynamics and performance. Many projects have failed miserably because of a lack of teamwork and not understanding the roles and responsibilities of the team members. It is important to note that in those failed projects, the team members were technically competent and had complementary skill sets to succeed in those projects. According to B. W. Tuckman, teams typically go through the stages of forming, storming, norming, performing, and transitioning (or adjourning).1 We will explore each stage and identify the appropriate management approach required for that stage. Stage 1: Forming 1. Team members getting to know each other 2. Group is immature 3. Sense of belonging to the group 4. Take pride in membership with the group 5. Trying to please each other 6. May tend to agree too much on initial discussion topics 7. Not much work is accomplished 8. Members' orientation on the team goals 9. Members understand the roles and responsibilities H1493 Ramu_p00i-284.indd 35 7/13/16 5:55 PM 36 Part I Six Sigma Fundamentals Stage 2: Storming 1. Team members voice their ideas 2. Understanding of the scope and members' roles; responsibilities will be put to test 3. Ideas and understanding start to conflict 4. Disagreements start to slow down the team 5. Not much work is accomplished 6. Necessary evil that every team member has to go through to position themselves on the team 7. Too much disagreement can completely stall team progress Stage 3: Norming 1. Team members resolve their conflicts 2. Team members agree on mutually acceptable ideas to move forward 3. Some work gets accomplished 4. Start to function as a team 5. Team members start to trust each other and share their ideas and work products without hesitation Stage 4: Performing 1. Team is effective, skills complement, and synergy is created 2. Team members realize interdependence 3. Develop ability to solve problem as a team 4. Large amount of work gets accomplished Stage 5: Transitioning (or Adjourning) 1. Team is disbanded 2. Team members go on with other activities of their work 3. If the project is continued with additional scope, team members may be changed 4. Team dynamic changes and tends to go back to one of the earlier stages 5. Major changes can result in going back to forming stage This is the typical evolution of team stages. Depending on the organization's culture, some stages may be shorter or longer, but the team still goes through them. H1493 Ramu_p00i-284.indd 36 7/13/16 5:55 PM Chapter 4 D. Team Basics 37 It is healthy for the team to go through these stages as it sets ground rules and expectations for team members. Team maturity, complexity of the task (project), and team leadership also have an impact on the stages. Recognition Recognition of the team's work is the often forgotten piece of team dynamics or, rather, is taken for granted. Even though team members are compensated monetarily for their time and skill, they should be recognized. Teams can be recognized in many ways, from a simple pat on the back by senior management to t hank-you notes, bulletin boards, organization-wide e-mails, newsletters, all-employee meetings, certificates of accomplishment, bonuses, stock options, and so on. Team Leadership The team leadership may vary depending on the maturity of the team and the stage the team is at based on the leader's perception. Examples of leadership activities during each of the stages include: Forming. Appropriate leadership style is directing: — Leader welcomes and encourages the team — Leader explains the roles, responsibilities, and goals of team members — Leader instructs the team as to what to do when, where, and how — Leader provides close supervision, exhibits directive behavior — Leader listens to team's feedback — Leader identifies opportunities for developing skills to meet team goals Storming. Appropriate leadership style is coaching: — Leader continues close supervision, exhibits directive behavior — Leader also exhibits supportive behavior — Leader increases the listening level to solicit the team's feedback — To keep the storming at an acceptable level (not detrimental to the task at hand), the leader may bring in a facilitator or use conflict resolution approaches. Norming. Appropriate leadership style is supporting: — Leader reduces the level of directive behavior and increases the level of supportive behavior — Leader encourages the team on decision-making responsibilities H1493 Ramu_p00i-284.indd 37 7/13/16 5:55 PM 38 Part I Six Sigma Fundamentals — Leader helps the team move to the performing stage before it can revert to an earlier stage — Leader emphasizes ground rules, scope, and roles and responsibilities Performing. Appropriate leadership style is delegating: — Since the team is mature, the leader reduces the levels of directive and supportive behavior in day-to-day functions — Leader continues to monitor the goals and performance of the team — Leader watches for any disruption in dynamics due to major changes in the organization Negative Team Dynamics If a team has several negative dynamics, this is more a reflection on the organizational culture than on the personalities of the individuals. If something is "acceptable" within the organization as a norm, that becomes the way of running the business. In other words, the organizational culture becomes the "enabler" of the many team problems that organizations face. Negative dynamics in the team can: • Have a negative impact on team member motivation • Hurt a team member's ego and self-esteem • Intimidate team members • Reduce the self-confidence of others • Increase stress and exhaust patience • Increase feelings of insecurity • Foster a lack of morale As a result, unchecked or unaddressed negative team dynamics may cause: • Goals and objectives of the project/task to not be met • Targets to be frequently revised to the team's advantage • The project to be cancelled • Project milestones and deadlines to be missed • Poor utilization of project resources • The project to overrun its cost targets • Turnover of key project team members Table 4.1 outlines common negative team dynamics and possible countermeasures. Chapter 1 of The Team Handbook discusses additional facilitation tactics.2 H1493 Ramu_p00i-284.indd 38 7/13/16 5:55 PM Negative dynamic Symptoms Probable causes Potential countermeasures Overbearing member(s) Team interaction is limited to a few individuals. The rest of the team is always in listening mode rather than participating in the discussion. Team is composed of a few influential members (senior management staff, founders, inventors), members with legitimate authority (investor, major shareholder, owner), subject matter experts, and so on. This may intimidate other team members, who hesitate to voice their opinions. With the support of the influential team member, the team leader reinforces roundrobin voicing of opinions, using methods like nominal group technique, conducting the meeting in a more informal setting, keeping experts and influential members as an extended team, and so on. Dominant member(s) Meeting discussion is chaotic and difficult to listen to or understand. Only a few members dominating the entire discussion. Dominant team members keep interrupting the conversation of other team members. Structure the agenda to provide equal participation for all team members. Effective moderation by team leader allows other team members to finish their thoughts. Team leader initiates round-robin to provide opportunity for every team member to be heard. Floundering Team is currently proceeding or performing in an unsteady, faltering manner. Lack of team direction. Some teams have highprofile team leaders from the organization, but they hardly ever attend meetings or team discussions. The organization is going through major changes, and no one is clear about the future of the team. During early stages of the team, more direction is required. Team members are overwhelmed. This can be due to multiple reasons. The organization may be going through major changes: leadership, downsizing, mergers and acquisitions, offshore transfers, and so on. Team leadership should keep the team focused by not getting distracted by events happening within the organization. Team leaders should address the concerns of the team members but not allow the team agenda to be hijacked by other events. Reinforce management support and commitment when team starts to challenge the purpose of the team. 39 Postponing of team decisions. This is related to lack of direction from the team leadership. If there is no clear direction, decision making gets difficult. Team leadership should be visibly present during the team meetings and decisions. Chapter 4 D. Team Basics H1493 Ramu_p00i-284.indd 39 Table 4.1 Common negative team dynamics and potential countermeasures. (Continued) 7/13/16 5:55 PM (continued) 40 Negative dynamic Symptoms Probable causes Potential countermeasures Reluctant participants Lack of participation, noncommittal feedback. Basically showing disinterest. Team member may not have any stake in the team's outcome. Intimidated by other team members or leaders. In the process of moving out of the current job function or organization. Fear of losing job or position by voicing opinions. Team leaders support the team members' active participation and protect the team members voicing their opinions. Unquestioned acceptance of opinions as facts Members present information without backing up data or analysis. Members present unfounded assumptions. Organizational culture. Lack of management by facts. Team leader requests supporting data, analysis, and conclusions that are statistically valid. Groupthink No public disagreements. Doubts expressed in private discussions. There are several other classical symptoms identified by researchers. Members fear group cohesiveness will be at stake if there are any disagreements. Putting group harmony as paramount. Bring independent members from outside to participate. Rotate roles and responsibilities of members at milestones. Management by fact. Feuding Hostilities resulting in heated arguments, slowed progress, low morale of the team. Conflict resolution not effectively handled by the team leadership. Lack of mutual respect between team members. Team operating ground rules not enforced. Confront the adversaries offline and not in the team meeting. Confronting in public can worsen the situation. Question the assumptions behind the analysis. Enforce discipline and emphasize mutual respect among team members. Restate the objective of the team as main focus. Part I Six Sigma Fundamentals H1493 Ramu_p00i-284.indd 40 Table 4.1 Common negative team dynamics and potential countermeasures. (Continued) 7/13/16 5:55 PM Negative dynamic Symptoms Probable causes Potential countermeasures Rush to accomplishment Incomplete data collection. Inconsistent analysis. Trying to get conclusion faster. Team under unrealistic deadline. Untrained team members. Looking for short-term gains. Team leadership asks for data collection, analysis, and statistical significance. Ask for alternate solutions. Revise the deadline to a more realistic one based on resources. Attribution Members make casual references. Members don't seek explanations, preferring psychological and emotional judgments. Similar to "rush to accomplishment" causes. Team leaders challenge the assumptions made by team members. Use devil's advocate approach. Ask for analysis behind the conclusions drawn. Discounting Members' opinions are ignored. Members do not seem to listen to each other. Sarcasm, low team morale. Digressions and tangents Discussion straying outside meeting agenda. Distractions. Meeting time not properly utilized; little is accomplished. Encourage mutual respect. Enforce discipline. Ask for clarification from the members providing opinions. Organization going through major change. Cultural issues. Lack of focus from leadership. Enforce compliance with agenda items and time allotment. Restate meeting ground rules. Redirect the discussions. Chapter 4 D. Team Basics H1493 Ramu_p00i-284.indd 41 Table 4.1 Common negative team dynamics and potential countermeasures. (Continued) 41 7/13/16 5:55 PM 42 Part I Six Sigma Fundamentals Define brainstorming, multivoting, and nominal group technique (NGT), and describe how these tools are used by teams. (Understand) Body of Knowledge I.D.3 3. D ecision-Making Tools Brainstorming Brainstorming is a process where a team develops as many ideas concerning a topic as possible, using various creative methods. Brainstorming is a powerful technique for soliciting ideas, and it is used extensively in many improvement activities at every stage of improvement or problem solving. This tool intentionally encourages divergent thinking through which, hopefully, all possible causes are identified. This is a team exercise and requires a good facilitator to get the ideas flowing. Brainstorming has two phases: the creative phase, in which a large number of ideas are generated, and the evaluation phase, in which the ideas generated are looked at for usefulness or applicability. The two phases should be separated by a time break, as different parts of the brain are used in each phase. At a minimum, a 10-minute break should be taken after the creative phase versus going directly to the evaluation phase. Criticisms or other distractions are not allowed during the creative phase. Team members should keep their minds open to all the possibilities no matter how wild the idea. The goal is to get as many ideas as possible. Facilitation can be used during the creative phase, but freewheeling also works well. Brainstorming is effectively performed with the help of a trained facilitator. The facilitator's job is to enforce ground rules and encourage ideas. A common tendency of brainstorming teams is to criticize the ideas instantly and discard them during the session. This will discourage team members from contributing for fear of being rejected. Team members must remember that there are no bad ideas. At this stage, quantity of ideas is given priority. A typical brainstorming session can generate between 25 and 40 ideas. If a flip chart is used to record ideas with a large group, two or more individuals should be used to capture all the ideas as they develop. You could also have each person say what they are thinking and then have them or someone else record the idea on a sticky note and put it on the wall. Some basic guidelines that should be followed in the creativity phase of brainstorming include: • No criticism, compliments, or questions • Wild ideas are welcome • Don't wait • Quantity is important (versus quality) • Hitchhike—build on previous ideas H1493 Ramu_p00i-284.indd 42 7/13/16 5:55 PM Chapter 4 D. Team Basics 43 During the evaluation phase, it is best to have a facilitator work with the group to look over the ideas in sequence. There are many ways to evaluate the ideas generated. One good starting point is to organize the list of things into like groups or categories (i.e., build an affinity diagram; see Chapter 7, Figure 7.2). The caution here is to not get overly critical, as there may be something in one of those "crazy" ideas that might actually work for the given situation. This is often true because of new technology or different ways of doing things that are not common in our organizations. To get the most out of brainstorming, before starting the activity review, look over the following idea-stopping responses with the team: • Don't be ridiculous • Let's shelve it for right now • It won't work here • Our business is different • Let's think about it some more • We did all right without it • It's too radical a change • Management won't like it • Where did you dig up that idea? • It's not practical • It's too expensive • You can't be serious • You can't do that • The technology will not allow that • Where will you get . . . ? • We've never done it before • I have something better • It's too risky • Let's be sensible • We'll never get it approved • The employees won't like it • It's good, but . . . • Let's check on it later • It's too much work • Let's get back to reality • That's been tried before H1493 Ramu_p00i-284.indd 43 7/13/16 5:55 PM 44 Part I Six Sigma Fundamentals • That's not my job • You do not know how we do things around here • That's too high-tech for us • It will never work In practical application, the team identifies the subject or problem at hand and writes it down on a whiteboard. It is important to clearly define the problem. This will keep the ideas on topic. For an issue that is unfamiliar to the team, it is acceptable to keep the scope open so that a wide range of ideas are generated. The team leader explains the problem or subject to the team members. The following example topics have the scope defined to facilitate the majority of ideas focusing on the defined area: • Contamination of polished surfaces before optical subassembly • Low attendance at ASQ section program meetings • Food menu for Thanksgiving dinner Following are examples with the scope wide open: • Global warming • Unemployment • Organizational culture The team is given a few minutes to think about the subject. In structured brainstorming the team leader opens up a round-robin discussion. This way everyone gets the opportunity to contribute. If someone doesn't have an idea at this time, they are allowed to pass and contribute during the next round. Team members are not allowed to criticize each other or evaluate the ideas at this stage. The individual recording the ideas can ask for clarity on an idea and phrases it the same way as the idea contributor. Rephrasing without the consent of the idea owner is not allowed. Everyone is allowed one idea at a time. Some members will have the urge to provide multiple ideas during their turn. The team leader should facilitate such situations. Members are allowed to develop an idea already cited by a fellow member. Quantity is more important than quality, so the team leader should encourage the team to keep the ideas flowing. All ideas are recorded on a whiteboard or flip chart. We will now look at an example of d efined-scope brainstorming: How can member attendance of ASQ section program meetings be improved? (problem rephrased as a question). Every major city in North America has a local ASQ section run by volunteers. A benefit of this section is the monthly program meeting. Unfortunately, these meetings draw a very low attendance (about 7%–10%) of members from the region, with at least 20% of the members attending once throughout the year. The program chair (responsible for ASQ section monthly meetings) leads the brainstorming session and the section chair may act as a facilitator. A team has been assembled with other section executives, past section chairs and/or executives, H1493 Ramu_p00i-284.indd 44 7/13/16 5:55 PM Chapter 4 D. Team Basics 45 section senior members, and members randomly selected from the membership database. One of the members volunteered as a recorder, and the team was given [illegible] eliminate redundancy during the consolidation. For a controversial or sensitive subject, the team leader may opt to collect the ideas and write them down on the board, maintaining anonymity of the contributors. Multivoting Multivoting complements NGT and can also be successfully used with brainstorming results. Even though this tool is typically used in combination with NGT, it can be a technique on its own. The consolidated ideas are numbered or lettered, and the team members are asked to prioritize the top 5 or 10 items that can be of significant influence on the problem. The team members are given 5–10 minutes to prioritize, and the results are tabulated. Let's return to the example of how to improve attendance at ASQ section program meetings. The members were asked to submit and prioritize ideas. As we saw, the diversified member group provided 34 ideas. Even though many of those ideas are good, the section may not have resources to address them all at one time. The section chair wants to select the five most important ideas to address in the next three years, and implement them in order of priority. Each team member selects the five most important ideas by placing a check mark by the idea. It is important for the facilitator to restate the objective and refocus the team to select ideas from the ASQ section point of view. If this facilitation is not done, you may end up with multiple ideas with an equal number of check marks. Once this is done and you have the five ideas that most team members have selected as significant for improving the attendance of a section program, the prioritization process has begun. This can be done through either a non-weighted (ranking) or a weighted approach. The members selected the following ideas, categorized into five themes, as having the most significant impact on improving section attendance: 1. Value. Bring in reputed speakers and present topics that are current 2. Logistics. Rotate program locations based on member concentration 3. Affordability. Do not charge for meeting and offer refreshments (e.g., pizza, snacks, sandwiches, coffee) 4. Outreach. Conduct some meetings on the local community college or university campus to attract students 5. Communication. E-mails twice per month, updated section calendar event web page The multivoting ranked approach outcome is shown in Figure 4.1. H1493 Ramu_p00i-284.indd 47 7/13/16 5:55 PM 48 Part I Six Sigma Fundamentals Venue: Caribou meeting room Date: 3-Feb-15 Subject: How can member attendance of ASQ section programs be improved? Scale: 1 (least important) to 5 (most important) Member Member Member Member Member Member Member Member Member 1 2 3 4 5 6 7 8 9 Executive Asponsor(s) 5 2 4 5 5 2 4 5 5 Total 37 B 2 4 3 3 4 4 3 3 4 30 C 1 5 5 4 3 5 5 4 3 35 D 3 3 1 2 2 3 1 2 2 19 E 4 1 2 1 1 1 2 1 1 14 Figure 4.1 Multivoting ranked approach example. In the multivoting weighted approach, the team rates rather than ranks the choices. This is like the $100 or 100 points approach, where the team member is asked to split $100 or 100 points among five choices. The multivoting weighted approach outcome is shown in Figure 4.2. As shown in Figure 4.1 and Figure 4.2, the two approaches produce similar rankings in this example. However, this is not always the case, which is why using both approaches can help a team focus on the most critical items. If two items have values that are close to each other, another round of voting can be conducted to select a clear winner. Note: While this example is not targeted to a specific ASQ section, the problem chosen for this example and the ideas generated are realities for most ASQ sections. The top choices and ranking were created to demonstrate the example rather than to provide solutions to the existing problem. Venue: Caribou meeting room Date: 3-Feb-15 Subject: How can member attendance of ASQ section programs be improved? Member Member Member Member Member Member Member Member Member 2 3 4 5 6 7 8 9 1 Executive 20 25 35 20 25 25 35 30 Asponsor(s) 30 Total 245 B 15 25 20 20 25 20 20 20 15 180 C 10 30 30 25 30 25 30 30 25 10 220 D 20 15 10 15 15 10 10 15 20 130 25 10 15 5 10 15 15 5 25 125 E There is NO ranking scale applicable to this approach. The column total should add up to 100 for all individual columns and the relative importance of A to E to be understood by the points allotted by each member (from that member's point of view). Overall relative importance is understood from reviewing the "Total" column. Based on consolidated input from all members, in this example, A is most important, followed by C, B, D, and E. Figure 4.2 Multivoting weighted approach example. H1493 Ramu_p00i-284.indd 48 7/19/16 5:02 PM Chapter 4 D. Team Basics 49 Explain how teams use agendas, meeting minutes, and project status reports, and how they support project success. (Understand) Body of Knowledge I.D.4 4. Communication Methods Team projects are reviewed through meetings. Effective meetings are key to project success as they provide continual updates of information and action to the team members. We need to be asking ourselves: • Are we discussing the right topic? • Do we have the right audience? • Do we have actionable discussions? • Do team members who attend the meeting know what they should do? • Was the time spent productive and worthwhile? Why are meetings not productive? • Overwhelming information • Too many presentation slides • Information unrelated to the agenda • Attendees not well prepared • Sending delegated attendees on short notice • Too many side conversations • Attendees using their smartphones to check e-mail and messages • Remote attendees calling in through virtual meeting infrastructure may be multitasking • Preparations are being made for the next meeting while still in the current meeting • Getting in arguments over "how to" while the meeting is still focused on "what to" • No actionable discussions—groupthink and philosophical agreements A worldwide productivity survey conducted by Microsoft revealed the following: • "People work an average of 45 hours a week; they consider about 17 of those hours to be unproductive (U.S.: 45 hours a week; 16 hours are considered unproductive)." H1493 Ramu_p00i-284.indd 49 7/13/16 5:55 PM 50 Part I Six Sigma Fundamentals • "People spend 5.6 hours each week in meetings; 69 percent feel meetings aren't productive (U.S.: 5.5 hours; 71 percent feel meetings aren't productive)."3 Ineffective meetings continue to haunt every organization as a major productivity detractor. The organization's culture may contribute a lot to the ineffective meetings. Taking a disciplined approach to meetings will help address many of the issues mentioned earlier. Meetings have to be conducted periodically to ensure continuity. An effective meeting includes the following: • Agenda. Meetings should not be initiated or attended without a clear agenda. The meeting subject is not the agenda. The agenda should be itemized: meeting subject, items required to be discussed, item presenters, and time allotment. Without a clear agenda and time allotment for agenda items, the meeting can easily get out of control and become unproductive. If it is a project meeting, the scope has to be presented to the team members to ensure that there is no scope creep. • Meeting logistics. This includes meeting room (for face-to-face meetings), virtual call-in infrastructure, and video capability. • Meeting minutes. The meeting minutes are a record of the meeting. Minutes are essential to ensure the key decisions made and the actions agreed on by the team members are formally recorded and keep the team members accountable. The minutes should be well drafted and unambiguous, and they should indicate the date and time of the completed meeting, meeting host, attendees, topics covered, decisions made, actions assigned (what, who, when), minutes reviewed and approved, and scribe name. One might also include "parking lot" items that are pending detailed discussions. Meeting minutes are important to project continuity. • Project status report. This is a periodic status report created by the project manager or team leader and circulated to all team members and management to list the status of the project, upcoming milestones, risks, and mitigation plans. Any unacceptable project variances and risks are addressed early in the project by reviewing the status reports and taking appropriate actions. Questions 1. Why is "storming" a necessary evil in the team stages? Discuss your experience in a team that went through the storming stage. Describe any lessons learned. 2. Why is recognition of a team after the successful completion of a project highly recommended? What are your recommendations for recognition for a Six Sigma team? H1493 Ramu_p00i-284.indd 50 7/13/16 5:55 PM Chapter 4 D. Team Basics 51 3. Discuss the effect of "groupthink" in a meeting. How do you ensure due diligence? 4. A team struggling to meet project milestones has repeatedly requested extensions from the management. This is a high-stakes project and the revenue stream is dependent on project success. You have been asked by your Black Belt to conduct a brainstorming session to identify causes of the team's lack of progress. Discuss the issue with your participants and put together a list of plausible causes. Apply the multivoting approach as well. 5. List the major causes of ineffective meetings in your organization. Research best practices for improving meeting effectiveness and share with your participants. H1493 Ramu_p00i-284.indd 51 7/13/16 5:55 PM Chapter 5 E. Quality Tools and Six Sigma Metrics Select and use these tools throughout the DMAIC process: Pareto charts, cause and effect diagrams, flowcharts, run charts, check sheets, scatter diagram, and histograms. (Apply) Body of Knowledge I.E.1 1. Quality Tools Table 5.1 shows several tools that are used across the DMAIC phases. These tools may be a simple check sheet to collect data or a complex multivariate analysis to identify the effect of critical variables. Most improvement projects can be conducted with easy-to-use basic quality and statistical tools. Let us start with the seven quality tools that are considered to be basic quality tools and are applicable in most improvement or problem-solving projects: Pareto charts, cause and effect diagrams, flowcharts, run charts, check sheets, scatter diagrams, and histograms. Pareto Charts The Pareto chart has been so widely used in recent years that "Pareto" is sometimes used as a verb. It is not uncommon to hear from managers to "Pareto" data for presentation. Some people who are not familiar with Pareto charts interchangeably use a bar graph to "Pareto" data. The true Pareto chart, however, is unique. It shows the data arranged in descending order of frequency of occurrence, the "trivial many" data are often pooled together as "miscellaneous" or "other" (represented by the last bar of the Pareto chart), and the chart contains a cumulative percent line with a secondary y axis. These characteristics make the Pareto chart more informative and useful than an ordinary bar graph. The Pareto chart helps us visualize the items charted as "vital few" and "trivial many" using the famous 80:20 principle of twentieth-century Italian economist Vilfredo Pareto. Joseph Juran is credited with being the first to apply this principle in quality improvement. 52 5 H1493 Ramu_p00i-284.indd 52 7/13/16 5:55 PM Table 5.1 Tools across DMAIC phases. Define Measure Analyze Improve Control Is-is not Check sheet Why-why Mistake proof SPC Pareto MSA Comparative Brainstorm Control plan Histogram Process capability indices DOE FMEA Sampling Timeline Benchmarking with baseline, best-in-class Hypothesis test Flowchart Gaging Run chart COQ/COPQ ANOVA Prioritization matrix Close loop automation Flowchart OEE C & E diagram Pugh concept selection 5S SIPOC diagram Process sigma level (with or without shift) C & E matrix Process capability indices Kanban Stakeholder analysis Process audit Scatter diagram Single piece flow Visual management— Andon Brainstorm Financial tools Stratification such ROI, NPV, IRR, RONA SMED Process audit Problem definition (what, where, when, who, and how many) Dashboard— RYG monitoring Time series analysis Pilot study A3 plan VOC Table DPPM/DPMO/ DPU/RTY metrics, software defect density, errors per transaction Regression analysis Process optimization Cross training Kano diagram Value stream mapping Power sample size Horizontal deployment (share improvement across organization) Standard work Project charter Equipment/tool correlation study Multivariate Safety and environmental factors Gemba walk Note: Some tools are applicable in more than one phase. The intent of this table is to show a variety of tools in various phases. SIPOC: supplier-input-process-output-customer VOC: voice of the customer MSA: measurement system analysis COQ: cost of quality COPQ: cost of poor quality OEE: overall equipment effectiveness ROI: return on investment NPV: net present value IRR: internal rate of return RONA: return on net assets RYG: red-yellow-green H1493 Ramu_p00i-284.indd 53 DOE: design of experiments ANOVA: analysis of variance C & E: cause and effect SMED: single minute exchange of die SPC: statistical process control 5S: sort, straighten, shine, standardize, sustain RTY: rolled throughput yield DPU: defects per unit DPPM: defective parts per million DPMO: defects per million opportunities 7/13/16 5:55 PM 54 Part I Six Sigma Fundamentals In the final assembly inspection example shown in Figure 5.1, the data are presented as a Pareto diagram based on frequency of occurrence. While these data are important, one might want to put their resources into issues that are critical to the customer or that have more financial impact. So the data are assigned weights based on criticality and multiplied by occurrence, and a Pareto diagram is created based on the weighted score. The table in Figure 5.1 shows the reprioritized defects based on criticality. Cost of repair or rework can also be used in place of weight, and the Pareto chart can be expressed in dollars. Cause and Effect Diagrams A thorough understanding of process inputs and outputs and their relationships is a key step in process improvement. The cause and effect diagram (also called the Defect code Defect description Occurrences Criticality Weight Weighted score A Scratches 15 Minor 10 150 B Stains 17 Minor 10 170 C Label smudge 12 Minor 10 120 D Dent 14 Major 25 350 E Device nonfunctional 5 Critical 100 500 F Broken LED 7 Critical 100 700 G Missing screw 3 Major 25 75 100 2000 1500 80% 80 20% 60 1000 Percent Relative importance (occurrences × weight) Final assembly inspection (weighted) 40 500 0 Defect code Weighted score Percent Cumulative % 20 Broken LED Device nonfunctional 700 500 33.9 24.2 33.9 58.1 Dent 350 16.9 75.1 Stains 170 8.2 83.3 Other 345 16.7 100.0 0 Figure 5.1 Pareto chart of final assembly inspection defect codes. H1493 Ramu_p00i-284.indd 54 7/13/16 5:55 PM Chapter 5 E. Quality Tools and Six Sigma Metrics Measurement Material Personnel Environment Methods Machines 55 Figure 5.2 Empty cause and effect diagram. Ishikawa diagram or fishbone diagram) traditionally divides causes into several generic categories. A large empty diagram as shown in Figure 5.2 is often drawn on a whiteboard or flip chart. This diagram is used as a next step to document the final list of causes from the brainstorming session. The participants in the session should include people with a working knowledge of the process as well as those with a theoretical background. For example, suppose a machining operation is producing surface defects. After a few steps of typical brainstorming, the cause and effect diagram would look like Figure 5.3. Measurement Material Repeatability Personnel Supplier variation Reproducibility Shifts Material variation Property Sk Stability Equipment Motivation Too Vibration Particle count Speed Lubricant Temperature Vibration Parameters Condensation Moisture percent Surface defects slo w atic Static discharge Environment Training Err tion ndi acy cur Ac Co e itud ill Att Bias Supervision Setting Tooling Methods Maintenance Condition Machines Figure 5.3 Cause and effect diagram after a few steps of a brainstorming session. H1493 Ramu_p00i-284.indd 55 7/13/16 5:55 PM 56 Part I Six Sigma Fundamentals CEDAC (cause and effect diagram with addition of cards) is an alternative approach employed by some organizations where the fishbone diagram is displayed on a huge wall or board and employees are encouraged to identify causes by writing on it or using sticky notes. The success of this approach depends on organizational culture and communication. Flowcharts A flowchart is a quality tool (and a business process tool) that helps individuals visualize a process in discrete steps arranged in the sequence of events. There are variations of flowcharts that can accommodate complexities in the process, for example, interactions between process steps, ownership, and process measures. Flowcharts can also be used as an improvement tool to understand current complexities, identify opportunities for removing redundancies and waste, and ensure the process is simplified and standardized. Once the process has been simplified and standardized, the flowchart may be used as a training tool and for auditing processes. Processes A process is a series of steps for producing products and/or services. A process is often diagrammed with a flowchart depicting inputs, a path that material or information follows, and outputs. An example of a high-level process flowchart is shown in Figure 5.4. Understanding and improving processes is a key part of every Six Sigma project. Steps in the development of a flowchart are as follows: 1. Determine the scope of the flowchart with boundaries 2. Write down the steps in the process 3. Rearrange where required to reflect the current sequence of steps 4. Draw the flowchart (use appropriate flowcharting symbols for ease of understanding) 5. Walk through the process to test the flowchart 6. Identify opportunities for removal of redundancies, waste reduction, simplification, and standardization 7. Communicate the flowchart to all stakeholders An example of a flowchart for replacement of a product under warranty is shown in Figure 5.5. Order receipt Credit check Inventory check Production Shipment Billing Figure 5.4 High-level flowchart for an order-filling process. Source: N. R. Tague, The Quality Toolbox, 2nd ed. (Milwaukee, WI: ASQ Quality Press, 2005): 257. H1493 Ramu_p00i-284.indd 56 7/13/16 5:55 PM Chapter 5 E. Quality Tools and Six Sigma Metrics 57 Start Customer identifies a product failure during use No replacement. Discard according to environmental guidelines No Customer verifies warranty conditions for replacement Yes Customer fills out warranty replacement form Attach the form with the defective product and send to warranty handling Customer support clerk processes the application Customer support staff sends a letter explaining the reason for disqualifying warranty claim Send the defective product for failure investigation No Customer support staff verifies warranty conditions for replacement Yes Place an order for product replacement A Warehouse clerk receives the order Physically retrieves a new product from the shelf Ships to the customer requesting replacement Customer receives replacement Figure 5.5 Basic flowchart for replacement of a product under warranty. H1493 Ramu_p00i-284.indd 57 7/13/16 5:55 PM 58 Part I Six Sigma Fundamentals Run Charts The run chart is used to identify patterns in process data. All of the individual observations are plotted in a time sequence, and a horizontal reference line is drawn at the median (Figure 5.6). A run chart is typically used when the subgroup size is one. When the subgroup size is greater than one, the subgroup means or medians are calculated and connected with a line, similar to a control chart. How- ever, run charts are different from control charts (e.g., X and R charts); run charts do not have statistical control limits to monitor variation. There are also related statistical tests that can be performed to detect any nonrandom behavior. Run chart tests can detect trends, oscillation, mixtures, and clustering. These are nonrandom patterns and suggest that the variation observed can be attributed to special causes. Lack of steadiness in a process can cause oscillation. In the example shown in Figure 5.6, the p-value for oscillation is 0.78, indicating that it is not significant (see Chapter 15 for a discussion of p-values). A trend can be either upward or downward due to, for example, tool wear or loosening of a fixture in a piece of equipment. Check Sheets Check sheets are used to observe or review a process, usually during execution of the process. Check sheets pre-categorize potential outcomes for data collection using sets of words, tally lists, or graphics. Figure 5.7 is an example of a completed Run chart for bond average strength 15.0 WB Avg 12.5 10.0 7.5 5.0 1 10 20 30 Number of runs about median: Expected number of runs: Longest run about median: Approx P value for clustering: Approx P value for mixtures: 40 45 62.49593 10 0.00141 0.99859 50 60 70 Observation 80 90 100 Number of runs up or down: Expected number of runs: Longest run up or down: Approx P value for trends: Approx P value for oscillation: 110 120 78 81.66667 5 0.21478 0.78522 Figure 5.6 Run chart analysis (using statistical software). H1493 Ramu_p00i-284.indd 58 7/13/16 5:55 PM Chapter 5 E. Quality Tools and Six Sigma Metrics 59 Paint color defect causes Day of the week Mon Tue Wed Thu Fri Sat Sun Weekly total l l 0 ll llll llll ll lll 19 Wrong pigment used lll l llll lll llll llll llll llll 30 Wrong color code from customer ll l ll 0 0 llll 0 10 Outdated base paint 0 0 l 0 lll 0 llll 8 Daily total 6 3 8 5 12 16 17 67 Executive Reason sponsor(s) Operator misread instructions Figure 5.7 Example of a check sheet. check sheet, in tabular format, used to collect data related to a paint mixing process. This simple tool provides a method of easy data collection. By collecting data on a check sheet, common patterns or trends can be identified. The basic steps in making a check sheet are as follows: 1. Identify and agree on the causes or conditions that are to be collected. 2. Decide who will collect the data, over what time period(s), and how the data will be collected. (Determine whether any training is required for staff regarding the types of data and the data collection process.) 3. Create a check sheet that will work within the operation where it will be used. 4. Conduct any training or briefing for an effective data collection. 5. Collect the data as designed to ensure consistency and accuracy of the information. Check sheets can be the basis for other analytical tools and are incorporated into attribute process behavior charts. Creating and using a check sheet helps keep a focus on continual improvement, and the simple act of using a check sheet may foster changes. Data collection is the basis for analysis and subsequent improvement and its importance should not be underestimated. Scatter Diagrams A scatter diagram (Figure 5.8) is used to explore the relationship between two sets of variables. This diagram provides a visual display of correlation between the variables. This tool should be used in conjunction with the cause and effect diagram. The scatter diagram is created with the independent variable as the x axis and the dependent variable as the y axis. If one is cause and the other is effect, then effect is the dependent variable and cause is the independent variable. In this diagram, the data are obtained in pairs (X, Y). Once the data pairs are plotted for the range of the axis, the plotted data can be interpreted. H1493 Ramu_p00i-284.indd 59 7/13/16 5:55 PM Part I Six Sigma Fundamentals 60 No correlation: Strong positive correlation: Scatter plot 3 2 3.5 3.0 Y Y 1 –1 1.5 –3 –3 –2 –1 0 X 1 2 1.0 100 3 Strong negative correlation: 200 300 X 400 500 400 500 Quadratic relationship: Scatter plot –1.0 Scatter plot 40 –1.5 30 –2.0 –2.5 Y Y 2.5 2.0 –2 –4 Scatter plot 4.0 –3.0 20 10 –3.5 –4.0 100 200 300 X 400 500 0 100 200 300 X Figure 5.8 Scatter diagrams. Histograms The histogram (Figure 5.9) is an easy-to-use tool for graphically summarizing continuous data collected from a process. The frequency of data occurrence is reflected as bars of various heights. Since data can be unique, they are grouped by intervals. The histogram shows the shape of the data, centering of the process, variation, and a rough distribution of the data. The histogram is helpful for comparing "before and after" improvement readily while waiting for a more detailed analysis. An initial indication of process capability may be seen by comparing the center and width of the distribution with the specification limits. The following are steps for developing a histogram: 1. Identify the process parameter to be analyzed 2. Collect the data to the required precision 3. Divide data into number of intervals (as a guideline, use the square root of number of samples n) 4. Arrange the collected data by interval 5. Draw a histogram based on the frequency of data falling at every interval We will see some examples of types of distributions and interpretation of process capability in the Measure phase of this book. H1493 Ramu_p00i-284.indd 60 7/13/16 5:55 PM Chapter 5 E. Quality Tools and Six Sigma Metrics Frequency 9.5 10.0 10.5 11.0 11.5 12.0 12.5 6 6 5 5 4 4 3 3 2 2 1 1 0 9.5 61 10.0 10.5 11.0 11.5 12.0 12.5 0 Freq1 Figure 5.9 Histogram. Additional Quality Tools The following quality tools are widely used alongside the seven quality tools. Control Charts A control chart (Figure 5.10) is used to monitor process stability and variability. Every process has natural variability from causes like people, equipment, method, X-bar and R chart of length Sample mean 5.0 4 3.5 4 +1SL = 4.440 – X = 4.067 44 4.0 12/15/12 +2SL = 4.813 4 4.5 –1SL = 3.694 –2SL = 3.322 3.0 Sample range +3SL = 5.186 5 5/5/13 1 6/2/13 5 6/27/13 –3SL = 2.949 8/23/13 9/22/13 10/14/13 11/17/13 12/22/13 1/19/14 Date 1 1 +3SL = 4.100 +2SL = 3.380 3 +1SL = 2.659 2 – R = 1.939 1 –1SL = 1.219 0 12/15/12 –2SL = 0.498 –3SL = 0 5/5/13 6/2/13 6/27/13 8/23/13 9/22/13 10/14/13 11/17/13 12/22/13 1/19/14 Date 1 – Figure 5.10 Example of X and R control chart. H1493 Ramu_p00i-284.indd 61 7/13/16 5:55 PM 62 Part I Six Sigma Fundamentals material, and environment. This is "common cause" variation. This variability is measured and drawn as control limits on the chart. A stable process will have process data plotted above and below the central line within the control limits. This is because a stable process has random variation. However, if any "special causes" enter the process, the process tends to go out of control. Examples of special causes include changes in processes, materials, operator skill, or environmental factors like temperature or humidity. Stratification In typical manufacturing or service industry data collection, the data have a mixture of multiple variables. As an example, if you are collecting data of process defectives, the data may come from different manufacturing lines, different process steps, different operators, different shifts, different days, different weeks, different factory locations, and so on. In a service example, you are collecting data of customer transaction time. These data may come from different operators, different complexities, different days, different weeks, different service locations, and so on. When you lump all these variables together and analyze the data, it is often difficult to make any interpretation. Hence, stratification is a data mining approach to help dissect data by variables and interpret the patterns and behaviors in the data set. Select and use these metrics throughout the DMAIC process: defects per unit (DPU), defects per million opportunities (DPMO), rolled throughput yield (RTY), cycle time, and cost of poor quality (COPQ). (Apply) Body of Knowledge I.E.2 2. Six Sigma Metrics Process performance is a measure of how the process is executing against established goals or statistical measures. Metrics can be identified throughout the DMAIC process (Table 5.2). Metrics with operational definitions are required to understand what to improve at the Define stage; the metrics are monitored at the Control stage. Nonconformance degrades process performance. Nonconformance with requirements or expectations is called a "defect" or "defective." A number of defects can appear in a single unit or service transaction. As an example, a physical product like a painted automotive part could have a scratch, dent, dirt, or nonuniform painted surface. All these are individual defects. In total, the part has four types of defects (four opportunities for defects). Even within the painted part, there could be three scratches, one dent, one with dirt, and one patch of nonuniform surface, for a total of six defects in the part. If we had 10 such parts and count the average defects per unit, this is the "defects per unit," or DPU. H1493 Ramu_p00i-284.indd 62 7/13/16 5:55 PM Chapter 5 E. Quality Tools and Six Sigma Metrics 63 Table 5.2 Examples of metrics by Six Sigma stage. Six Sigma stage Examples of metrics Define Describe the problem objectively DPU, DPMO, RTY, COPQ, Cpk, Ppk, RPN, takt time Measure P/T, % GRR, % agreement Analyze p ≥ 0.05 Improve DPU, DPMO, RTY, COPQ, Cpk, Ppk, RPN Control DPU, DPMO, RTY, COPQ, takt time Irrespective of whether the painted automotive part has one or six defects, you would call the part a defective part. The average proportion of defective parts in a production quantity is calculated to measure process capability. Process performance in terms of defect and defective measures usually includes the following. Defects (Deficiencies or Nonconformities) per Unit (DPU) DPU is calculated as the total number of defects divided by the total number of products produced in some time period (e.g., per day). This metric is used when the area under inspection is large in size or volume, for example, the number of defects on a painted chassis or textile. Defects (Deficiencies) per Million Opportunities (DPMO)1 To calculate the number of opportunities, it is necessary to find the number of ways each defect can occur on each item. In a hypothetical product, the product is inspected for the following defects: scratch, dent, broken, and bent. There are four opportunities for defects. If there are 10 units, this totals 40 opportunities. If there are four defects (irrespective of type of defect), DPMO = (Total number of defects ÷ Total number of units × Number of opportunities per unit) × 106 Manufacturing Example2 Process: Painting automotive product Types of opportunities for defects: Scratch, dent, dirt, nonuniform thickness (bump or base metal visible) Opportunities = 4 Number of production units = 100 H1493 Ramu_p00i-284.indd 63 7/19/16 5:02 PM 64 Part I Six Sigma Fundamentals An inspector performed a thorough visual inspection of 100 production units and found the following: 1 scratch in 4 units, 1 dent in 2 units, dirt in 2 units, and nonuniform thickness in 2 units, for a total of 10 defects in 100 units inspected. DPU = 10/100 = 0.1 The DPMO is (10/100 × 4) × 106 = 25,000 Service Example Service: Finance department sending invoice to customer Types of opportunities for defects: incorrect address, incorrect amount, incorrect due date Opportunities = 3 Number of invoices sampled = 100 An auditor performed a thorough review of 100 invoices and found the following: 2 incorrect address, 3 incorrect amount, and 3 incorrect due date, for a total of 8 defects in 100 invoices sampled. DPU = 8/100 = 0.08 The DPMO is (8/100 × 3) × 106 = 26,667 Rolled Throughput Yield (RTY)3 RTY applies to the yield from a series of processes and is found by multiplying the individual process yields. If a product goes through four process steps whose yields are Process step #1 = 99.4%, Process step #2 = 98.7%, Process step #3 = 95.1%, and Process step #4 = 99.0%, then RTY = 99.4% × 98.7% × 95.1% × 99.0% = 92.37%. This means for every 100 products that are started, we end up with 92 good, conforming products. The other 8 products may be able to be reworked, repaired, or regraded. However, they are not fit for shipping to customers without further processing, of which the organization incurs the cost of poor quality. Throughput yield can also be calculated by knowing DPU = e–DPU. Sigma Levels4 A sigma level is the quality level of the process—the higher the sigma level, the higher the quality level and the fewer defectives per million units produced or service transactions rendered. There are two types of sigma level calculations: sigma H1493 Ramu_p00i-284.indd 64 7/19/16 5:02 PM Chapter 5 E. Quality Tools and Six Sigma Metrics 65 level with Motorola 1.5 sigma shift and without the shift. As an example, 3 sigma level without shift (0 shift) is 2700 defective parts per million (DPPM). However, with 1.5 sigma shift, it is 66,807 DPPM. Six Sigma Quality level without shift is 2 parts per billion (ppb) and with 1.5 sigma shift is 3.4 DPPM. Cycle Time Cycle time is the time it takes for a process to be completed, from start to end. As a Six Sigma Yellow Belt, you may occasionally have to also measure wait time or queue time. This is the time that the material (product or paperwork) sits idle before the transformation is started. Lead time—another term used in improvement efforts—is the time it takes for the material to arrive from the time an order is placed at your supplier. Your customer might ask the lead time of your product or service. It is important that you take your supplier's lead time into account when making commitments to your customer. Lead time is a metric that is used interchangeably with cycle time by many practitioners. Every organization may have its own definition. In your organization, you may want to define and document the operational definition to be consistent. Cost of Poor Quality (COPQ) COPQ is interchangeably used with cost of quality (COQ). Some organizations choose to distinguish COPQ as the cost of nonconformance and COQ as the cost of conformance (Figure 5.11). However, in some publications, COQ is referred to as the overall cost that includes both the cost of conformance and the cost of nonconformance. The cost of nonconformance is the sum of internal and external failure costs the organization incurs. Examples of internal failure costs are scrap, rework, repair, and retest. Examples of external failure costs are customer return, replacement, and administration. The cost of conformance is the sum of the Total cost of quality Costs Quality level that minimizes total quality costs Cost of nonconformance Cost of conformance Zero percent quality level, percent good 100% Figure 5.11 Traditional quality cost curves. H1493 Ramu_p00i-284.indd 65 7/13/16 5:55 PM 66 Part I Six Sigma Fundamentals appraisal and prevention costs the organization incurs to ensure products and service conform to specifications and customer requirements. Examples of appraisal costs are inspection, administrative costs for quality functions, and supplier surveillance. Examples of prevention costs are training, supplier qualification, risk assessment, and process capability measurement. There are several hidden costs that are not measured by organizations. Examples are lost customers, unused capacity, planning delays, and time spent resolving complaints. Hidden costs are estimated to be as high as three to four times the visible costs. COPQ and COQ are measured as percent ratio compared with the cost of goods sold or the cost of goods manufactured. Some organizations also compare them with revenue, sales, and so on. It is important to choose the right denominator in order to have a meaningful ratio. Improvement in COPQ should come from a reduction in failure costs. Improvement in COQ should come from a reduction in appraisal costs and an increase in prevention costs. (See "Cost-Benefit Analysis" in Chapter 16 for more on COPQ.) Questions 1. Review Table 5.1 and add tools that you think could be used in DMAIC stages based on your past experience. 2. What is the difference between an affinity diagram (Chapter 7) and a cause and effect diagram? List the applications of each. 3. What differentiates a Pareto chart from a bar graph? Develop a Pareto chart and a bar graph for the data from your business and explain what additional information is provided in the Pareto chart. 4. Measure the height of each class participant and present it in the form of a histogram. 5. Explain the importance of understanding hidden costs in a cost of quality measurement. H1493 Ramu_p00i-284.indd 66 7/13/16 5:55 PM Part II Define Phase Chapter 6 Chapter 7 A. Project Identification B. Project Management (PM) Basics 67 H1493 Ramu_p00i-284.indd 67 7/13/16 5:55 PM Chapter 6 A. Project Identification Define the voice of the customer and describe how customer needs are translated into quantifiable, critical-to-quality (CTQ) characteristics. (Understand) Body of Knowledge II.A.1 1. Voice of the Customer One of the key organizational drivers is customer and market knowledge—the ability of an organization to determine the requirements, needs, expectations, and preferences of customers and markets. Also necessary are the relationships with customers and the ability to determine the key factors that lead to customer acquisition, satisfaction, loyalty, and retention, and to business expansion and sustainability. The voice of the customer (VOC) is a process for capturing customer-related information. This process is proactive and continuously innovative to capture stated, unstated, and anticipated customer requirements, needs, and desires. The goal is to achieve customer loyalty and to build customer relationships. The VOC might include gathering and integrating survey data, focus group findings, lost customer analysis, lost bids analysis (potential customers), warranty data, complaint logs and field reports, and any other data and information that affect the customer's purchasing and relationship decisions. These days, with the surge in social media, organizations should also be capturing and analyzing data from social networks for the VOC. Translating customer needs into quantifiable critical to quality (CTQ) characteristics is the execution side of the business. It involves taking customer inputs and designing the product or service, ensuring that the product is manufacturable and the service is consistently delivered to the customer. There are many tools that are used to ensure the customer needs are designed in. Although not commonly used by organizations, quality function deployment (QFD) is one such tool. QFD (Figure 6.1), also known as the house of quality (HOQ), has three stages. Planning house, design house, and manufacturing house (Figure 6.2) cascade explicit and perceived customer needs into a controllable manufacturing or service control 68 6 H1493 Ramu_p00i-284.indd 68 7/13/16 5:55 PM Chapter 6 A. Project Identification 69 8 Co-relationships 2 Technical requirements 1 3 4 5 Customer requirements Relationship matrix Comparison with competition Action notes 6 Comparison with competition 7 Target values How How Product planning matrix Part planning matrix Process planning matrix What How What What Figure 6.1 Map to the entries for the QFD matrix. Figure 6.2 Sequence of QFD matrices for product, part, and process planning. point. Most organizations use a disciplined design and development process that use tools like the Pugh concept selection matrix, failure mode and effects analysis (FMEA), and the process capability study. These tools, along with a structured approach to product development, help ensure the customer needs are translated into CTQ requirements for the products and services. H1493 Ramu_p00i-284.indd 69 7/13/16 5:56 PM 70 Part II Define Phase Describe how projects are identified and selected as suitable for a six sigma project using the DMAIC methodology. (Understand) Body of Knowledge II.A.2 2. Project Selection A series of successful Six Sigma projects is likely to lead to more project ideas than it is possible to undertake at one time. Some sort of project proposal format may be needed, along with an associated process for project selection. Project proposals are often required to include a precise statement of the problem definition and some preliminary measures of the magnitude (importance) of the problem, including its impact on the goals of the organization. (An example of a project proposal template is available on the CD-ROM accompanying this book.) A project selection group, which includes Master Black Belts, Black Belts, organizational champions, and key executive supporters, establishes a set of criteria for project selection and team assignments. In some companies the project selection group assigns some projects to Six Sigma teams and other projects to teams using other methodologies. For example, problems involving extensive data analysis and improvements using designed experiments would likely be assigned to a Six Sigma team, while a process improvement involving waste reduction might be assigned to a lean manufacturing team. New-product design should follow design for Six Sigma (DFSS) guidelines. The project selection criteria are always a key element of furthering the organization's goals. One key to gauging both the performance and health of an organization and its processes lies with its selection and use of metrics. These are usually converted to financial terms such as return on investment, cost reduction, and increases in sales and/or profit. Other things being approximately equal, the projects with the greatest contributions to the bottom line receive the highest priority. However, some organizations may select and assign projects for Six Sigma Yellow Belts and Green Belts as learning opportunities. Typical project selection criteria are strategic importance, bottom line improvement, technical complexity, stakeholder risk, and change management.1 An organization is unlikely to invest resources in projects that do not align with organizational strategy. A good starting point is to look at the A3 Planning sheet. A3 Planning for any organization is the blueprint for strategic goals and objectives. The first step is to ensure alignment with strategic goals and objectives. Equally important is to select projects that will make a positive impact on the bottom line. A more experienced cross-functional Six Sigma team will likely be assigned a project with a high level of technical complexity and stakeholder risk. Projects requiring a high level of change management will be handled by team members with a significant number of project completions under their belts. It takes experience to understand the impact of changes. In order to avoid Six Sigma members making subjective decisions in selecting projects, it may be beneficial to develop a template to assign scores for various projects. Criteria and weights may be assigned based on consensus. An example of a project selection matrix can be found on the CD-ROM accompanying this book. H1493 Ramu_p00i-284.indd 70 7/13/16 5:56 PM Chapter 6 A. Project Identification 71 Following is an example of a Six Sigma project where a risk analysis and a strengths- weaknesses-opportunities-threats (SWOT) analysis are performed to assess the merit of pursuing the project. Example A proposed Six Sigma project is aimed at improving quality to a level that will attract one or two new customers. The project will cost $3 million (M). Previous experience indicates that the probability of getting only customer A is between 60% and 70%, and the probability of getting only customer B is between 10% and 20%. The probability of getting both customer A and customer B is between 5% and 10%. One way to analyze this problem is to make two tables, one for the worst case and one for the best case, as shown in Table 6.1. Assuming that the data are correct, the project will improve enterprise profits between $1M and $2.5M. When estimating the values for these tables, the project team should list the SWOT that the proposal implies. A thorough study of this list will help provide the best estimates (see Figure 6.3). Table 6.1 Risk analysis table. Worst-case profit Outcome Best-case profit Probability Profit × Probability Probability Profit × Probability A only $2M .60 $1.2M $2M .70 $1.4M B only $2M .10 $0.2M $2M .20 $0.4M A&B $7M .05 $0.35M $7M .10 $0.7M None –$3M .25 –$0.75M –$3M 0 $0M Expected profit = $1M Expected profit = $2.5M Strengths: High-quality product Monthly quantity commitment Tooling cost by customer Just-in-time concepts Online interface Product mix Weaknesses: Pricing Union plant High employee turnover Aging equipment—downtime issues Opportunities: Potential industry leadership More growth Long-term contract Threats: Competition from start-ups Labor force Union plant Unstable market Unstable labor force Figure 6.3 A format for SWOT analysis. H1493 Ramu_p00i-284.indd 71 7/13/16 5:56 PM 72 Part II Define Phase Identify end users, subject matter experts, process owners and other people or factors that will be affected by a project, and describe how each of them can influence the project. (Understand) Body of Knowledge II.A.3 3. Stakeholder Analysis Stakeholders are those who have a vested interest in the process and/or its products and outputs. Generally, stakeholders of an organization include customers, suppliers, employees, investors, and communities. Stakeholder interest and involvement with the process may change over time depending on economic, contractual, and other influences. ISO 9000:2015 has introduced a new term, "interested parties," which is more comprehensive than "stakeholders." End users are those who eventually consume the product or service. An interim customer for an organization can be a dealer, distributor, or wholesaler. This should not be confused with the end user. Subject matter experts (SMEs) are those who have demonstrated skill and competency in an area that is important to the existence and sustainability of the business. Process owners are those who have responsibility for the definition, execution, maintenance, and improvement of a specific process. Process owners are usually formally recognized in this role through related documentation (e.g., procedures, work instructions, documentation approval authority), through their job/position description, or through the organization chart. In some cases process owners may also be referred to as SMEs. Personnel involved with process design usually have a specific interest in systems, subprocesses, and individual steps within processes. The most effective methods of process improvement utilize teams representing process owners and all stakeholders because: • Stakeholders have the best knowledge base about the process • Stakeholders tend to have the best ideas for process improvement • Stakeholders are often the most aware of unintended consequences of process changes • Stakeholders' buy-in is usually necessary to implement real process improvement The stakeholders in a process are: • Process operators and managers from all shifts • Process customers, internal and external • Process suppliers, internal and external H1493 Ramu_p00i-284.indd 72 7/13/16 5:56 PM Chapter 6 A. Project Identification 73 • Process design personnel • Maintenance personnel • Others impacted in some way by process changes A typical stakeholder analysis (Figure 6.4) involves identifying key stakeholders for a given project. A score of –10 to 10 is assigned for attitude, activity, power, and interest. The attitude rating is found by multiplying attitude by activity. The power rating is found by multiplying power by interest. Ideally, the project champion and the leader want people with not only high power but also high interest. Similarly, people with high activity also have high attitude for the success of the project. Identify Customers It is important to identify and understand the customers of a product or process. Depending on the maturity of the product or process, the customers may already be known, but it is still a good practice to identify them. Methods used to identify customers include: • Marketing analysis data • Brainstorming • SIPOC Customers can be internal; for example, one division of an organization may sell a component or service to another division within the same organization. Just because it is the same organization does not mean we can take the customer for granted. The customer may choose to purchase the product or service from a competitive source, making the internal division a likely target for shutdown. In today's globalized market, everything is possible. The organization may have interim customers, like dealers or distributors. And then there is the end user, who consumes the product or service from the organization. Knowing your customer is key. Many organizations struggle with the fundamental question, Who is your customer? It may not be very obvious for some organizations. Some level of data collection and analysis is required. Internal and external customers should be identified when applicable. Customers can be grouped into segments like the following: • Internal and external • Age groups, especially for consumer products • Geographical location, including climate, language, and ethnicity • Industry type (e.g., construction, agricultural) Where possible, a listing of customers within a segment should be constructed. When a project team proposes changes of any kind, customers (internal and external) must be consulted or, at a minimum, the customers' concerns must be represented. H1493 Ramu_p00i-284.indd 73 7/13/16 5:56 PM Values for attitude, activity, power, and interest were assigned using the following rating scales: Attitude Activity Power Interest –10 (strongly against) 0 (completely passive) 0 (no effective power) 0 (no interest) Stakeholder categories Contract manufacturer to to to to 10 (strongly for) 10 (strongly active) 10 (powerful influence) 10 (very interested) Relevant stakeholders Code Attitude Activity Attitude rating Power Interest Offshore manufacturing C 0 4 0.00 5 3 Power rating 15.00 Management Your organization M 10 5 50.00 8 10 80.00 Employees Trade compliance team E 5 10 50.00 5 10 50.00 Service providers Brokers B 5 3 15.00 5 2 10.00 Government US Customs G 0 0 0.00 0 0 0.00 The reference line in the interest/power plot represents the ideal balance for a vital stakeholder. Points above the line represent stakeholders with potentially high influence on the success of the project; they can either be powerful supporters or powerful detractors. Interest/Power Plot Vital 10 M Power 8 6 B E C 4 2 G 0 0 2 6 4 8 10 Interest The reference line on the left side of the attitude/activity plot marks the point at which stakeholders are considered potentially adversarial to the project. Points to the left of this line represent stakeholders who could present roadblocks. The reference line on the right marks the point at which stakeholders are considered potentially supportive of the project. Points to the right of this line represent stakeholders who could provide assistance in overcoming roadblocks. Attitude/Activity Plot 10 Adversarial E Supportive Activity 8 6 M C 4 B 2 G 0 –10 –5 0 5 10 Attitude Text from MINITAB Quality Companion help summary. Figure 6.4 Stakeholder analysis. Source: Adapted from Janet Jacobsen, "Getting Green with Lean," Making the Case for Quality, September 2009, 4. H1493 Ramu_p00i-284.indd 74 7/13/16 5:56 PM Chapter 6 A. Project Identification 75 Use SIPOC (suppliers, inputs, process, outputs, customers) to identify and define important elements of a process. (Apply) Body of Knowledge II.A.4 4. Process Inputs and Outputs A process is a step or sequence of steps that uses inputs and produces a product or service as an output. Every process has inputs and outputs. Inputs are traditionally categorized as the 5Ms—man (person), material, methods, machines, and Mother Nature. Some organizations also include management, money, and measurement system (as the measurement system may have an impact on the output). Outputs are usually products (hardware, software, systems, etc.) or services. Figure 6.5 depicts the model of a process. Processes are often made up of subprocesses. For example, a part may be produced through a process that has a machining step. This machining step may be thought of as a process whose steps might include clamping, turning, plunging, facing, and so on. In addition, the plunging step is a process in itself. In a similar manner, a payroll process has subprocesses that include gathering time clock information, making deductions, and so on. The deduction process itself could be thought of as having subprocesses for tax deductions, insurance, and so on. Process Identification When planning to study a process or system, it is very important to first identify the boundaries to work within. There are many ways to do this; most are not complex and can be easily implemented with common process knowledge and some investigation. When defining a process it is important to define its start and end points—its boundaries. If, for example, a team is charged with improving a process, team members need to know these process boundaries. C ross-functional processes may incur subprocess boundaries defined by the organizational structure, geography, and so on. Inputs • People (Man) • Materials (Resources) • Methods • Mother Nature • Management • Measurement system Process Transform inputs into outputs Outputs • Products – Hardware – Software – Systems – Data – Information • Services Figure 6.5 Process diagram/model. H1493 Ramu_p00i-284.indd 75 7/13/16 5:56 PM 76 Part II Define Phase The two primary tools used to identify process boundaries are the basic process model identified in Figure 6.5 and the SIPOC diagram in Figure 6.6. The basic process model provides a quick high-level look at the process, but, in some cases, may be too simplistic to provide an improvement team with a clear understanding of the process/problem to work on and the boundaries of where and when to stop. The SIPOC diagram template in Figure 6.6 can be enhanced by also capturing the requirements of the process and customer. Understanding the boundaries of the improvement project and/or process does not inhibit outside-the-box thinking; it merely provides clear guidelines on what to deal with as daily activities and improvement activities are performed. Taking the time to actually list or draw the components of the process will assist in visualizing it and being able to find issues more quickly than might have otherwise been possible. When identifying the process it is important to recognize that processes usually affect multiple departments and organizations. Crossing functional areas (departments) and organizations (suppliers, intercompany) can add challenges to an improvement project. The first step in recognizing the challenges is to understand the organizations and functional areas involved with the process. As noted, the SIPOC diagram can help in identifying these organizations and functional areas as process suppliers and customers. The flowchart (especially the "swim lane" style) and process map are other tools that can be used to help recognize these interactions. Challenges associated with these interactions include, but are not limited to: • Process ownership (e.g., two or more areas think they own the process and have final decision authority on changes) • Sharing of information (e.g., proprietary issues, hiding poor performance) • Commonality of measures (e.g., finance usually measures things in dollars, production uses defects or productivity, engineering considers productivity and design completion) • Process knowledge or expertise (e.g., manufacturing may not fully understand how the supply chain works or the requirements) If the challenges identified are significant, they should be included as potential risks for the project so associated mitigation activities can be performed. SIPOC templates for both the basic SIPOC diagram and the SIPOC diagram that captures requirements are provided on the CD-ROM accompanying this book. Questions 1. You have been asked to develop a new breakfast menu item for a restaurant chain. Identify your customers (using appropriate tools), capture the voice of the customer using a mock participant group, and determine the product (including packaging) and service requirements. H1493 Ramu_p00i-284.indd 76 7/13/16 5:56 PM Inputs Resources required by the process to obtain the intended output. Process Top-level description of activity. Input boundaries Process being reviewed Output boundaries Figure 6.6 Basic SIPOC diagram. Outputs Deliverables from the process. Note: deliverables can be hardware, software, systems, services, data, information, and so on. Customers Any organization that receives an output or deliverable from the process. Note: can also capture systems/ databases that receive outputs, information, data, and so on. Chapter 6 A. Project Identification H1493 Ramu_p00i-284.indd 77 Suppliers Providers of the required inputs/ resources to ensure that the process executes as planned. 77 7/13/16 5:56 PM 78 Part II Define Phase 2. Develop a SIPOC for the example in question #1. 3. Discuss the merits and disadvantages of tools used for customer identification. 4. Identify the criteria used for a Six Sigma project selection. What is the rationale for using these criteria? H1493 Ramu_p00i-284.indd 78 7/13/16 5:56 PM Chapter 7 B. Project Management (PM) Basics Describe the purpose of a charter and its components: problem statement, project scope, baseline data, and project goal. (Understand) Body of Knowledge II.B.1 1. Project Charter Project Charter and Problem Statement A charter is a document that states the purpose of a project. It serves as an informal contract that helps the team stay on track with the goals of the organization. A charter should contain the following points: • Problem statement. Identifies what needs to be improved • Purpose. Establishes goals and objectives of the team • Benefits. States how the enterprise will fare better when the project reaches its goals • Scope. Provides project limitations in terms of budget, time, and other resources • Results. Defines the criteria and metrics for project success—including the baseline measures and improvement expectations The problem statement is a summation of what requires improvement. A problem statement clearly indicates • Statement of fact (as observed by customer): what, who, where, when, how many • Project goal of accomplishment (success factors)—described objectively; uses guidance like SMART goals—specific, measurable, achievable, realistic, and time bound 79 7 H1493 Ramu_p00i-284.indd 79 7/13/16 5:56 PM 80 Part II Define Phase In order to determine project goals, project baseline data are collected. The data can be related to items where improvement is required. Progress is made in comparison with the baseline data. Examples include: Eight nonfunctional assemblies manufactured from March 10 to March 20, 2015, were returned by a customer in Fremont, California. Goal is to have zero customer returns. Twenty percent of the calls made by customers from Alameda County in California in 2014 indicate the average permit approval time was 2 weeks against the specified 1 week. Goal is to have 0% complaints. Project Scope The purpose of documenting the project scope, or boundaries, is to ensure a common understanding of what the project team, and its associated resources, will work on and what is outside those defined boundaries. The scope is usually defined, at least in part, based on the problem statement, which gives the project its initial focus. Using the problem statement, experience, and tools like SIPOC, brainstorming, and Pareto charts, the scope of the project can be defined and documented. Project Metrics Project timelines and activity plans can become little more than paperwork if meaningful performance measurements are not included. These measurements or metrics should link directly to the project goals and through them to the benefits for the enterprise. For example, if a goal is to increase process throughput by 25%, a key metric might be cycle time. The project's intermediate objectives and documentation need to include incremental cycle time reduction measures. Project measures are typically linked to a specific project, usually for the life of just that specific project, and they are often manifested as: • Percent of work accomplished on time (schedule performance index) • Percent of work accomplished on budget (cost performance index) • Other similar measures (e.g., availability of resources, quality of key deliverables) • Finance metrics like net present value (NPV), return on investment (ROI), payback period, and internal return rate (IRR) Project Planning Tools Project planning tools include project charters, project management plans, milestone charts, Gantt charts, project schedules, critical path, and goal and objective statements or bullets. The number of tools used and the depth of data contained in the tools vary based on the project size and scope. Larger projects often have more documentation since they take more time and expend more resources. Project H1493 Ramu_p00i-284.indd 80 7/13/16 5:56 PM Chapter 7 B. Project Management (PM) Basics 81 documentation is controlled and maintained (i.e., updated) during the life cycle of the improvement project. Project Closure The project charter is an excellent tool to use as a measure of project completion, as it establishes the scope, goals and objectives, and time frame for the project. A review of the charter against documented project results is often sufficient for closing a project. The project sponsor may want an independent review or assessment prior to formal project closure. This is typically done using an audit approach. Another method of proving that the project achieved its intent is analysis of project measures. A postmortem or "lessons learned" session is conducted by the project team to review things that went well and things that could be improved. This summary is used for planning future projects, leveraging any known best practices, and preventing reoccurrence of any past failures. This learning helps strengthen organizational knowledge. Explain the purpose and benefits of a communication plan and how it can impact the success of the project. (Understand) Body of Knowledge II.B.2 2. Communication Plan Communication is key to the outcome of a project, be it a simple or complex project. A simple project may require daily or weekly meetings with project members meeting face-to-face or through virtual media to update the status of the project and discuss any new risks encountered. A complex project, however, may require a formal communication plan. This means setting up a communication protocol (what, who, where, when, how, and how frequently), escalation protocol, escalation threshold (when to escalate), communication effectiveness verification, and so on. Adding to the challenge is a project team that is spread across geographies (distance and time zones), has different cultures, and has a varying level of infrastructure. There may be a need for h igh-frequency real-time project updates, as any delay in communication could result in project delay and cost overrun. Having a plan provides structure to communicate the right amount at the right time. While people generally say that there is no such thing as "overcommunication" and that more communication is always good, we need to be cognizant that overcommunication can impact productivity of the team. This may result in team members reading lots of communication rather than being productive. Hence, a communication plan can help with the right amount of communication at the right time. H1493 Ramu_p00i-284.indd 81 7/13/16 5:56 PM 82 Part II Define Phase Define work breakdown structure (WBS) and Gantt charts and describe how they are used to plan and monitor projects. (Understand) Body of Knowledge II.B.3 3. Project Planning Project planning is a disciplined approach to monitoring how and when a project will be accomplished. You may have heard the quote "Failing to plan is planning to fail." Exactly! Planning for a project involves thinking through the project stages, identifying steps, a timeline, milestones, resources, risks, and so on. The Gantt chart is a tool used for planning projects. This chart has activities from start to finish, the timeline, the duration, milestones, resources, and interdependence between activities. Activities identified from start to finish are called the work breakdown structure (WBS). WBS is developed by the project team members by brainstorming. First, high-level activities are identified, and then the team drills down to the subactivities for every high-level activity. By identifying these activities, the project manager can accurately know the progress and delays and can assign or relocate resources to ensure the project stays on schedule. An example of a Gantt chart and template are provided on the CD-ROM accompanying this book. As with many of the tools and processes listed in this book, there is a lot of information available in various references on project planning and project management. There is even a professional certification available just for project management. In this book, however, only the basics of project planning to assist in daily work are discussed. Effective project planning requires skills in the following areas: • Information processing • Communication • Resource negotiations • Securing commitments • Incremental and modular planning • Ensuring measurable milestones • Facilitating top management involvement1 H1493 Ramu_p00i-284.indd 82 7/13/16 5:56 PM Chapter 7 B. Project Management (PM) Basics 83 Select and use various PM tools: activity network diagrams, affinity diagrams, matrix charts, relations charts, and tree diagrams. (Understand) Body of Knowledge II.B.4 4. Project Management Tools Activity Network Diagrams The activity network diagram (AND), also known as the arrow diagram, displays the sequential order in which tasks are carried out in a project (see Figure 7.1). The diagram illustrates the efficiency of the schedule for the entire project. It can also reveal any potential scheduling and resource problems in the sequence planned. A main benefit of the arrow diagram is the calculation of the "critical path" of the project. This is the flow of critical steps in which a delay in any of the steps will affect the duration of the entire project. A project manager looks at the critical path closely to ensure resources are adequately planned to help make up for any delays in the project. Form and train analysis team (5 days) Start Formulate and publish RFP (10 days) Establish reply protocol (2 days) Receive and process proposals (5 days) Announce results (1 day) Finish Test software (2 days) Install software (1 day) Figure 7.1 Example of an activity network diagram. H1493 Ramu_p00i-284.indd 83 7/13/16 5:56 PM 84 Part II Define Phase Guidelines for Constructing an Activity Network Diagram Project team members start with brainstorming all the project tasks for every stage. The brainstorming is not sequential; inputs are received at random. Next, the team members write each task on a card or sticky note. The team must determine the correct sequence of the tasks (this may be an iterative process, as the team may go back and forth on some tasks). The team asks three questions for each task: 1. Which tasks must happen before this one can begin? 2. Which tasks can be done at the same time as this one? 3. Which tasks should happen immediately after this one? Once the team has agreed on the sequence, the sticky notes are placed on the diagram in sequential order. Time should flow from left to right and concurrent tasks should be vertically aligned (for ease of visualization). Sticky notes are arranged in such a way that circles are drawn between them to depict "events." An event marks the beginning or end of a task. Thus, events are nodes that separate tasks. This is why some practitioners call this useful tool a "node diagram." The tasks are supplemented with a data box of four grids: earliest start (ES), earliest finish (EF), latest start (LS), and latest finish (LF). Data from the grids are used to calculate slack time for each task. Slack time is the time a task can be delayed without impacting the overall project duration. Hence, by definition, there is no slack time for the tasks that are in the critical path. A step-by-step approach for developing an activity network diagram can be found on ASQ's website (. Affinity Diagrams An affinity diagram (Figure 7.2) is a display of brainstormed ideas, survey results, and any type of inputs arranged by affinity or an overarching theme. The affinity diagram complements brainstorming and organizes a large number of ideas into their natural relationships. When the team is overwhelmed with facts and ideas, issues seem too large and complex to grasp, or group consensus is necessary, the team arranges the ideas in an affinity diagram. This tool is very helpful in analyzing customer qualitative data and feedback. Convergence can also be accomplished by asking brainstorming participants to collect data on the various causes for a future reporting session. At the outset, it may appear that the data can be interpreted just by eyeballing them. However, grouping them by theme or affinity provides a more effective analysis. There is a definite advantage to using this tool. We are all bombarded with information on a daily basis and receive all kinds of inputs. Our brain is not wired to process information from different categories if they are arranged at random. Guidelines for Developing an Affinity Diagram A team related to the subject of discussion is assembled in a physical room or virtual network. The problem statement is clearly written down by the facilitator. H1493 Ramu_p00i-284.indd 84 7/13/16 5:56 PM Chapter 7 B. Project Management (PM) Basics 85 Problem: What are some of the ways to reduce cycle time for process A? Machine Personnel • Run machine faster • Assign more people • Get a new machine • Provide additional training • Apply new controls • Reduce setup time • Simplify machine operations Vendor • Improve vendor communication • Use cell phone to contact vendor • Have additional sources • Work with vendor to improve quality and delivery • Let Joe run the process/ machine • Provide help during setup Infrastructure • Reduce paperwork • Improve forklift uptime • Replace the conveyor • Purchase a new overhead crane • Ensure prompt delivery of route sheets Maintenance • Better lubricant • Reliability-centered maintenance • More frequent lubrication • More prompt response to maintenance calls • Reduce resupply time Figure 7.2 Example of an affinity diagram. Team members clarify the statement in case of any questions. The team is given a specified amount of time to write down their ideas on sticky notes (one idea per note). When time elapses, the facilitator collects the inputs and puts the sticky notes on a sheet of brown paper or butcher paper. Team members work together to group the inputs by theme or common topic. This is affinity. Depending on the number of inputs, the team may create subgroups or merge subgroups to form a super group. Any duplicate inputs are removed. Users often get confused between the cause and effect diagram and the affinity diagram. Even though the brainstormed inputs are grouped in the cause and effect diagram, there is a cause and subcause relationship among them. In the affinity diagram, the grouping is based on the overarching topic or theme. A step-by-step approach for developing an affinity diagram can be found on ASQ's website (affinity.html). Matrix Charts A matrix diagram is used to display relationships between two or more groups (set or products or entity). There are many types of matrix diagrams depending on the number of groups studied. H1493 Ramu_p00i-284.indd 85 7/13/16 5:56 PM 86 Part II Define Phase Determine the most suitable software package Options Criteria Compatibility 0.25 Cost 0.3 Ease of use 0.40 Training time 0.05 Total Package A 1.00 0.45 1.20 0.15 2.80 Package B 0.25 1.20 0.80 0.05 2.30 Package C 0.75 0.45 1.60 0.20 3.00 Package D 0.50 0.90 0.40 0.10 1.90 Figure 7.3 Example of a prioritization matrix. The most popular and commonly used matrix is the L matrix. This provides the interrelationship between two groups. Groups typically have multiple attributes. The relationship is attribute to attribute between the groups. A classical example of this tool is to compare various suppliers on multiple attributes like quality, cost, delivery, and responsiveness (see Figure 7.3). Other types of matrix diagrams are the T, Y, C, and X diagrams. The most recognizable of the matrix charts is the prioritization matrix.2 A step-by-step approach for developing a matrix chart can be found on ASQ's website (overview/matrix-diagram.html). Relations Charts A relation chart (also called a relationship diagram or matrix) provides interrelationships in the form of cause and effect. This e asy-to-use tool helps team members explore the causes and effects of each item by pointing the arrow toward the effect. This approach is typically used when the problem or issue at hand is complex and every input from the brainstorm could potentially have multiple causes and effects. Relationships r = weak š = moderate = strong Pizza not hot enough Delivered late Traffic jam š Oven heater error š Heat insulation quality Difficulty finding address r Toppings not as per order Wrong pizza delivered Burnt crust Did not understand customer accent r r Clerical error during order receipt Order not clearly identified r Mix-up on the delivery shelf r § § § Figure 7.4 Example of a relationship matrix. H1493 Ramu_p00i-284.indd 86 7/19/16 5:02 PM Chapter 7 B. Project Management (PM) Basics 87 Guidelines for Developing a Relations Chart A problem statement or the objective of the diagram is documented on a sticky note. The team brainstorms ideas about the issue and writes them on cards or notes. Inputs already presented in an affinity diagram or cause and effect diagram may also be used. The ideas are placed side by side and the team explores whether an idea is a cause or an effect of another idea. The question "Does this idea cause or influence any other idea?" is repeated for every idea. The team draws arrows from each idea to the ones it causes or influences. Count the arrows in and out for each idea. Write the counts at the bottom of each box. The ones with the most arrows are the key ideas. • Note which ideas have primarily outgoing (from) arrows. These are basic causes. • Note which ideas have primarily incoming (to) arrows. These are final effects that also may be critical to address. • Also review the ideas with fewer arrows incoming and outgoing from idea. They may be important as well. A step-by-step approach for developing a relations chart can be found on ASQ's website (overview/relations-diagram.html). Tree Diagrams A tree diagram (also known as a critical to quality tree diagram) is used to analyze and display subtopics and topics branching out from the main topic. This diagram (Figure 7.5) is similar to an organization chart. Sometimes it is flipped Tables rejected Welds Paint Sprung Broken Spatter Runs Scratches Shallow Moisture Viscosity Handling Settings Capacitor Bent (setting not known Bad tubing Clamped wrong Poor specifications Clamping instructions missing Figure 7.5 Example of a tree diagram showing a fault tree (used to study defects and failures). H1493 Ramu_p00i-284.indd 87 7/13/16 5:56 PM 88 Part II Define Phase counterclockwise from left to right. The head of the organization is your main topic, subordinates and their staff and their organization are subtopics, and so forth. This diagram can be effectively used in a team setting to solicit inputs and map out the subtopics. An example of this application is root cause analysis of complex topics that can have multiple possibilities. Guidelines for Developing a Tree Diagram Identify a key topic and put it on the wall. Ask the team to brainstorm and provide input as to what causes the main topic. The team may not always provide input at the right hierarchy, but this does not mean that the input is useless or that it should be discarded. Collect the input and place it in the diagram. It can always be promoted up in the tree hierarchy or pushed down in the tree. Once all the inputs are arranged with branches and subbranches, the team should review the diagram and verify that the causes and subcauses are in the right hierarchy level. More details on a step-by-step approach for developing a tree diagram can be found on ASQ's website ( ). Explain how tollgate or phase reviews are used throughout the DMAIC lifecycle. (Understand) Body of Knowledge II.B.5 5. Phase Reviews Tollgate or phase reviews are periodic progress reviews conducted for Six Sigma projects. The project manager and the project team may identify significant milestones at which the project should be reviewed. Milestones may be aligned with the natural stages of the Six Sigma structure (i.e., Define-Measure-Analyze-ImproveControl). Every organization is different. Some organizations set up entry and exit criteria for every stage to ensure all the necessary due diligence is completed before moving to the next stage. There may also be significant milestones between stages. As an example, recognizing the need for a Six Sigma project, building stakeholder consensus, and obtaining sponsor approval may likely be a milestone. Setting up a data collection system could be another milestone. The project manager and the team have to recognize the appropriate stages to plan the reviews. The purpose of this periodic review is to ensure that the project follows the necessary structure, deliverables are met, risks are anticipated and mitigated, project cost and time are closely monitored, and customer and other stakeholders are not negatively impacted. A Six Sigma tollgate review template can be found on the C D-ROM accompanying this book. H1493 Ramu_p00i-284.indd 88 7/13/16 5:56 PM Chapter 7 B. Project Management (PM) Basics 89 Questions 1. What are the key components of a project charter? Develop a project charter for the examples provided on page 80. 2. Evaluate key challenges of managing a virtual team. Be sure to include complexities like geography and languages. 3. Describe the importance of understanding critical path in a project. 4. Develop a prioritization matrix that you will use in picking a new real estate property (residential or commercial). Assign weighting based on relative importance. 5. Suggest examples of questions that you would ask during a tollgate phase review. H1493 Ramu_p00i-284.indd 89 7/13/16 5:56 PM Part III Measure Phase Chapter 8 Chapter 9 Chapter 10 A. Basic Statistics B. Data Collection C. Measurement System Analysis (MSA) 91 H1493 Ramu_p00i-284.indd 91 7/13/16 5:56 PM Chapter 8 A. Basic Statistics Define, calculate, and interpret measures of central tendency (mean, median, and mode) and measures of dispersion (standard deviation, range, and variance). (Apply) Body of Knowledge III.A Central tendency is one of the key attributes used in our day-to-day expression of measure. Mean, also known as "average," is a frequently used measure. Examples of mean in daily use include the following: the mean weight of a product sold is 100 grams, the mean time between equipment failures is 20,000 hours, and the mean distance to target is 10 meters. Median is another measure of central tendency used extensively in economics (e.g., median household income). Mode is also used in data analysis as the most occurring event. For data that are normally distributed, mean, median, and mode are the same. If the distribution is skewed to either the left or the right, the median will be away from the mean. The average represents a set of observations or data that are added together and divided by the total number of data points. This provides the central value of the observations. This measure is very widely used because of its ease of computing; no advanced knowledge of statistics is required. Although the average is a useful measure for making quick decisions, it is not robust. This measure can be skewed by extreme data. To find the average of the data set {11, 7, 1, 5, 3, 9, and 13}, first add all the data and then divide by the number of data points. (11 + 7 + 1 + 5 + 3 + 9 + 13)/7 = 7 Median is the central value of a set of observations or data arranged in ascending or descending order. If the number of values in the data set is an odd number, then the median is simply the value in the middle of the ordered data set. To find the median, first arrange the data set {11, 7, 1, 5, 3, 9, and 13} in ascending order. 1 3 5 7 9 11 13 Ascending order: H1493 Ramu_p00i-284.indd 92 7/13/16 5:56 PM Chapter 8 A. Basic Statistics 93 Next, find the middle value of the ordered data set. In this example, 7 is the median. If the data set is even, the median is the average of the two middle values. In this data set, interestingly, the average (mean) and the median are the same. However, there is no mode. Mode is the value in the data set that occurs most frequently. Since the values in this data set appear only once, there is no mode. Mode is easily identified by glancing at the data set; no additional steps are required. If additional data were added to the data set, it would look as follows: {11, 7, 7, 1, 5, 3, 9, 7, and 13} There have been added. Now the mode is also 7. If in a data set, mean, median, and mode are equal, the data set tends to be normally distributed. The distribution of the above data set is a small data set, and hence the classical bell shape is not evident. Data sets with more than 30 data points are generally considered large and adequate to make statistical decisions.1 Central tendency alone can be misleading without understanding dispersion. Measures of dispersion—range, variance, and standard deviation—are important for knowing how tightly the data are packed or spread around the central value. For a simple measure like range, we use the extreme values' minimum and maximum to describe variability. For standard deviation, an expression of the number of "sigma" is used to describe dispersion. The spread of the sample is also referred to as dispersion or variation and is usually quantified with either the sample range (defined as the highest value minus the lowest value) or the sample standard deviation. Range is an easy measure of dispersion. This can be done by visually spotting the lowest and highest values in the data set and subtracting them. This approach may be most appropriate for a quick answer and to make a conservative estimate. Variance and standard deviation are more robust measures for dispersion. Range can be easily influenced by extreme outliers in the data set. The sample standard deviation is the more sophisticated metric and is defined as $s = \sqrt{\sum(x - \bar{x})^2/(n-1)}$ where $\bar{x}$ = the sample mean or average n = sample size This formula produces an estimate of the standard deviation of the population from which the sample was drawn. If data for the entire population are used (rare in practical applications), the population standard deviation is defined as $s = \sqrt{\sum(x - \mu)^2/N}$ where μ = the population mean or average N = population size H1493 Ramu_p00i-284.indd 93 7/13/16 5:56 PM 94 Part III Measure Phase Due to the complexity of these formulas, one could use a calculator with standard deviation capabilities or Microsoft Excel or statistical software. The shape of the sample refers to a smooth curve that serves as a sort of umbrella covering, approximately, the tops of the bars in the histogram. In this case, it appears that the sample came from a normally distributed population. Other descriptors of shape include kurtosis, symmetry, and skewness. The following data represent a sample of critical dimensions of a chemical deposition operation. What conclusions can be reached by looking at the data set? 5.551, 5.561, 5.392, 5.479, 5.456, 5.542, 5.423, 5.476, 5.298, 5.499, 5.312, 5.319, 5.317, 5.314, 5.382 The charts in Figure 8.1 reveal information about the sample data that is not obvious from the data list, such as: • The spread of the sample • An indication of the shape of the sample • Center of the sample Spread 5.250 Frequency 5.30 5.325 5.400 C12 5.475 5.550 Critical dimension Individuals chart Mean 5.408 StDev 0.0879 N 15 LB 1 6 1 .455ge 1 2 1 0 0 8 0 6 0 4 0 2 0 0 5.50 5.50 C12 1 8 1 6 1 4 1 2 1 0 0 8 0 6 0 4 0 2 0 0 Critical dimension distribution Center Normal 5.250 5.325 5.400 5.475 5.550 5.45 5.40 5.35 5.30 5.55 5.50 5.35 5.45 C12 5.40 5.55 5.50 C12 Critical dimension Individual chart Normal—95% CI 5.7 5.1 5.2 5.3 5.4 5.5 5.6 99 Mean 5.408 StDev 0.0879 N 15 AD 0.471 P value 0.210 95 90 80 70 60 50 40 30 20 10 5 Percent Frequency • Fitting of normal distribution of the sample (explained later in this chapter) 5.1 5.2 5.3 5.4 C12 5.5 5.6 5.7 1 Figure 8.1 Example of a data set as illustrated by a frequency distribution, individual plot, histogram, and probability plot. H1493 Ramu_p00i-284.indd 94 7/13/16 5:56 PM Chapter 8 A. Basic Statistics 95 Table 8.1 Summary of descriptive measures. Name Symbol Formula/description Central tendency Mean $\bar{x}$ = Σx/n Median Formula/description Mode Middle number in sorted list Most frequent number Measures of dispersion Range R Sample standard deviation s High value – low value $\sqrt{\sum(x - \bar{x})^2/(n-1)}$ Part III Measure Phase Example In the data set shown in Figure 8.1: • The mean = (sum of the values) ÷ (number of values) = Σx/n = 81.121/15 = 5.408. • The median of the 15 values would be the eighth value when the sample is sorted in ascending order, in this case 5.392. If there is an even number of values, the median is obtained by averaging the two middle values. Of the three measures, the mean is the most widely used in quality engineering applications like control charts. The sample mean is often denoted as x with a bar above it and pronounced "x-bar." A summary of measures for central tendency and dispersion is shown in Table 8.1. Questions 1. Calculate the mean, median, and sample standard deviation for the following data set and provide your conclusions. 8.46, 8.77, 10.16, 10.51, 9.71, 10.89, 8.50, 11.21, 8.78, 9.19, 8.70, 9.31, 11.57, 10.69, 10.75 2. What are the challenges in considering only the average (mean) when making decisions? 3. How do you calculate the median if the data set has an even number of data points? H1493 Ramu_p00i-284.indd 96 7/13/16 5:56 PM Chapter 8 A. Basic Statistics 97 4. How are the sample standard deviation and population standard deviation calculated? When is it appropriate to use range? 5. If the bell curve is hugging toward the center, would you conclude that the variation is small or large? 6. What are the challenges and usage of measures of central tendency and measures of dispersion? H1493 Ramu_p00i-284.indd 97 7/13/16 5:56 PM Chapter 9 B. Data Collection Define, develop, and use data collection plans, including data collection methods, data accuracy and integrity, and how data are gathered. (Apply) Body of Knowledge III.B 1. Data Collection Plans Data collection is performed in an organization for various reasons: • Legal, regulatory, or statutory requirements • Analysis, improvement, and knowledge management • Contractual requirements of customers Irrespective of the reasons, data collection can be very expensive if it is not planned and implemented. Many organizations tend to collect more data than required. Answering some basic questions—such as what, why, where, when, who, and how (5W1H)—before starting to collect the data can help make the data collection more effective. Where possible, if real-time data acquisition from equipment is more effective and reduces human errors and data transfer errors. A typical data collection plan (Table 9.1) includes: What to measure — What do you want to measure? — Type of measure — Operational definition (e.g., cycle time, lead time, process time; these terms can have different meanings in different organizations) 97 91 H1493 Ramu_p00i-284.indd 97 7/13/16 5:56 PM H1493 Ramu_p00i-284.indd 98 Table 9.1 Data collection plan. Define what to measure Name of parameter or condition to be measured Define how to measure Type of measure Operational definition x or Y attribute or discrete data, product, or process data Measurement defined in such a way as to achieve repeatable results from multiple observers Measurement or test method Visual inspection or automated test? Test instruments are defined Procedures for data collection are defined \ Data tags needed to stratify the data Data tags (e.g., time, date, location, tester, line, customer, buyer, and operator) are defined for the measure Sampling method and sampling frequency Who will collect the data? Data collection method Manual? Spreadsheet? Computer based? Who will do it? Person(s) assigned State who has the responsibility Sample plan What? What measure is being collected Where? When? How many? The location How the data often the number collection data are of data collected points collected per sample Responsibility for measurement system qualification and release? Responsibility for measurement system qualification Who will measure? Control plan, FMEA, customer specification, manufacturing work instructions CTQ vs critical to process (CTP) matrix are typical sources of input for "what to measure" 7/13/16 5:56 PM Chapter 9 B. Data Collection 99 How to measure — Measurement or test method — Data tags need to stratify the data — Data collection method Who? When? (Data collection point) — Process step or physical location Who will measure? — Responsibility to measure (or collect) the data Sampling plan — How often? Frequency) — Timing and how frequent When? (Data collection point) — How much data will be collected? (Number of data points to be statistically valid) Define and distinguish between these types of data. (Understand) Body of Knowledge III.B.2 2. Qualitative and Quantitative Data The term "qualitative data" is derived from "quality" or "attributes." Qualitative data are expressed in words like "tall," "short," "hot," "cold," "long," "wide," and so on. Certain process measures are expressed only in qualitative data. Consumer experience and perceptions are measured qualitatively. With the rise of social media, big data analytics plays a major role in qualitative data analysis. An example of such analysis can be done using tools like Wordle ( ), a website where you can construct "word clouds," and trending features in social media software applications. The term "quantitative data" is derived from "quantity." Quantitative data are expressed through discrete and continuous data. Examples of discrete data are number of defects, number of deficiencies in a product, or errors made in service functions. There are no partial values, like half a defect. Continuous data can be any number of possibilities between two whole numbers; for example, the length of a widget can be 10 mm or 10.1 mm or 10.001 mm and so on. It can be any number of decimals or fractions that the measurement method and technology will practically allow. Examples of continuous data are product dimensions and service quality delivery cycle time. While continuous data are more informative for decision making, data collection can be expensive. Discrete data are easier to H1493 Ramu_p00i-284.indd 99 7/13/16 5:56 PM 100 Part III Measure Phase collect and more widely used than continuous data for quality measures. Data collection is fundamental to the statistical methods for analyzing discrete and continuous data. The ASQ Certified Six Sigma Green Belt Handbook provides statistical methods for analyzing both types of data. Define, develop, and use data collection plans, including data collection methods, data accuracy and integrity, and how data are gathered. The method to be used for gathering data, and how frequently it will be gathered, should be defined. Describe who and data collection plans are important. (Understand) Body of Knowledge III.B.3 3. Data Collection Techniques There are several methods for collecting data: • Surveys. This tool is used when a big sample size of data needs to be collected. Inputs are quick and often the first instinct from the input provider. Response rates are usually low, but inexpensive to collect. The quality of the survey feedback can vary significantly based on how the survey was created. • Face-to-face interviews. This method provides highly reliable data, but the data are expensive to collect. The interviewer should be willing to commit time and provide honest feedback. The interviewer's body language and emotions provide additional perspective to data collection, which is not available when soliciting inputs through surveys. • Focus groups. In this method, a group of individuals is assembled to obtain perceptions, thoughts, beliefs, and opinions about a product or service. It is similar to the face-to-face interview in that the interviewer may be able to obtain direct feedback. However, the interactions among the focus groups participants may be skewed by dominant participants. Having an experienced moderator will help obtain unbiased feedback. • Mystery shopping. This method is used by organizations to solicit data anonymously by having shoppers try out the organization's products and services. The shoppers are trained to ask certain questions, procure a service, make a complaint, and collect data from their experience. The organization analyzes the inputs provided by mystery shoppers and uses this information to improve its existing products, services, systems, and processes. It may reward employees who personify the organizational value, but it is discouraged from punishing employees who did not perform well during the mystery shopper experience. An H1493 Ramu_p00i-284.indd 100 7/13/16 5:56 PM Chapter 9 B. Data Collection 101 important aspect of this approach is that the shoppers should not be seen as a threat. • Customer feedback. Customer feedback may be solicited in many ways: surveys, face-to-face meetings, 1-800 calls, complaints, returned materials due to failures, and so on. Errors in market share is another indirect customer feedback. All these are lagging indicators. Engaging customers in the early stages of the product and service design, soliciting requirements, and receiving inputs at all stages of development are proactive methods for capturing data. • Automatic data capture. Automatic capture is a real-time data capture. This may be expensive to set up, due to interfacing the hardware and software with the source where the data are generated. This prevents errors in the data and the associated cost of correcting the error, and it also prevents wrong decisions made from erroneous data. One of the main advantages of the automatic data capture is the availability of the data to take action. There is no time lag between data collection and availability. This may be important when the risks are high, such as in financial, healthcare, and security management. A classic example is alerting a customer when fraud has been detected on the customer's account. • Manual data capture. In manual data collection, resources go to the source where data are generated and physically collect the data. They either write down the data or capture them electronically. This process is not only slow but may also become expensive depending on the resources required to capture the data. One-on-one data collection methods, like focus groups and face-to-face interviews, have a high integrity of data and provide an opportunity to clarify answers with the respondents, whereas a data collection method like a survey has a low response rate (approximately 10%–15%). Additionally, improperly constructed surveys can result in misleading conclusions. Manual data collection includes the use of tools like checklists and check sheets. A checklist has a standard set of items/questions that are required to be verified/completed to ensure that the item(s) that the checklist was created for and confirm each item's fitness for use. In another example, a nurse asks a patient a list of questions and collects data before sending the patient to the doctor. A check sheet is used to tally the occurrence of an event or incident. For example, a process may be producing different types of defects on a product. A tally mark is made on a check sheet to capture the occurrence of each type of defect. See Chapter 5, "Quality Tools and Six Sigma Metrics," for additional information and application. Where manual data entry is involved, it is more efficient to use data coding to avoid repetitive recording of numbers and errors due to fatigue. Decoding may be applied depending on the analysis to be performed. H1493 Ramu_p00i-284.indd 101 7/13/16 5:56 PM 102 Part III Measure Phase Example An inspector is measuring the diameter of a machine part. If the data are expected to fall between the upper and lower specification limits, repetitively typing the measurement data may lead to errors. The measurement values can be coded as a single-digit number representing the full measurement value. An important aspect of this approach is that we should still be able to arrive at the measurement value after decoding (see Table 9.2). Table 9.2 Coding—decoding. Coding Decoding Actual measurements Coded value Coded value Actual measurements 10.120 1 1 10.120 10.121 2 2 10.121 10.122 3 3 10.122 10.123 4 4 10.123 It is important to ensure that the data are collected with accuracy and integrity. Accuracy of the data depends on data collection method, technology used, verification due diligence, and so on. The integrity of the data depends on whether any bias is associated with collecting and reporting the data. Techniques for Ensuring Data Accuracy and Integrity Even sophisticated data collection and analysis techniques can be defeated if the data are entered with errors. Common causes of errors include: • Units of measure not defined (e.g., feet or meters?) • Closeness of handwritten characters/legibility (e.g., 2 or Z?) • Inadequate measurement system resolution/discrimination • Rounding off measurements and losing precision • Emotional bias resulting in distortion of data • Inadequate use of validation techniques—using guesswork or personal bias • Multiple points of data entry—opportunity for inconsistency and errors • Poor instructions or training causing erroneous data entry • Ambiguous terminology • Error-proofing techniques, automation, or H1493 Ramu_p00i-284.indd 102 7/13/16 5:56 PM Chapter 9 B. Data Collection 103 Some steps to minimize errors in data collection include: • Have a carefully constructed data collection plan • Calibration schedule for data collection equipment • Conduct repeatability and reproducibility (R&R) studies on measurement system • Record appropriate auxiliary information regarding units, time of collection, conditions, measurement equipment used, name of data recorder, and so on • Use appropriate statistical tests to remove outliers • If data are transmitted or stored digitally, use an appropriate redundant error correction system • Provide clear and complete instruction and training Questions 1. Put together a data collection plan for errors generated at a hospital. (Choose either medical or administrative errors or both based on your experience.) 2. Discuss why an operations definition is important for data collection. 3. Discuss why organizations are performing their decisions based on qualitative data. 3. What data are gathered over discrete data, and discuss the pros and cons of each. 4. Provide an example of the type of data collection method you would recommend for a specific scenario. 5. What are the recommendations to reduce or prevent errors for manual data collection? H1493 Ramu_p00i-284.indd 103 7/13/16 5:56 PM Chapter 10 C. Measurement System Analysis (MSA) Define precision, accuracy, bias, linearity, and stability, and describe how these terms are applied in the measurement phase. (Understand) Body of Knowledge III.C.1 1. MSA Terms Measurement system analysis (MSA) is an area of statistical study that explores the variation in measurement data due to: • Calibration. Drift in average measurements of an absolute value. • Accuracy. Closeness of agreement between the average of one or more measured results and a reference value. • Precision. Closeness of repeated readings to each other. Knowing the precision of a measurement tool and its equipment helps process owners understand the random error during the Measure phase. A random error is a component of measurement error that varies in an unpredictable manner. Measurement system variation, Precision (P) is used in relation to tolerance (T) to calculate the P/T ratio during the Measure phase. • Stability. Drift in absolute value over time. Drift in equipment explains why the process appears to go out of control at certain intervals. Even though the process might not have shifted, the equipment may indicate that the process is out of control. This is monitored by measuring a controlled sample on a periodic basis and monitoring the control chart from those data. • Repeatability. Variation in measurement when a single appraiser measures the same unit many times on the same equipment under the same conditions. Reviewing repeatability during the Measure phase helps process owners understand the suitability of the equipment. 104 H1493 Ramu_p00i-284.indd 104 7/13/16 5:56 PM Chapter 10 C. Measurement System Analysis (MSA) 105 • Reproducibility. Variation in measurement when measured by two or more appraisers multiple times. Reviewing reproducibility during the Measure phase helps process owners understand the variability due to human inability in reproducing the same measurement result interpart trial. • Linearity. Accuracy of measurement at various points of measuring range in the equipment. Understanding linearity during the Measure phase helps process owners understand why the measurement is consistent across the measurement range of the equipment. • Bias. Difference between the observed value and true value with respect to a standard master at various measurement points of the measuring range. (Often in practice accuracy and bias are used interchangeably.) Understanding bias during the Measure phase helps process owners understand why the equipment is not accurate and that they may have a need for calibration and adjustment of bias closer to the true value. Until the early 1990s MSA was used extensively in measurement laboratories and was less known to the industrial world. After the inception of the QS-9000 (now ISO/TS 16949) standard in the automobile industry, the importance of MSA was well understood by other sectors as well. An important issue for the Six Sigma Yellow Belt practitioner here is that in the quest for process variation reduction, the measurement system should be one of the first things analyzed for two reasons: • All data from the process are, in effect, filtered through the measurement system • It often represents the most cost-effective way to reduce variation Even statistical process control (SPC) experts have begun to write their SPC flows with "conduct an MSA study" as a starting step. MSA is actually that important. It is not uncommon for measurement systems to have an error of 40%–50% of the process specification. Describe how and why GR&R is used in the measure phase. (Understand) Body of Knowledge III.C.2 2. Gauge Repeatability & Reproducibility (GR&R) Repeatability is the equipment measurement variation expressed as standard deviation. Measurements are taken from the same equipment by one appraiser over a short period of time. See Figure 10.1. H1493 Ramu_p00i-284.indd 105 7/13/16 5:56 PM 106 Part III Measure Phase – Gauge repeatability (one appraiser) is ≈ 5Gage σ (X $\bar{i}$ i – X $\bar{i}$) 2 n – 1 Standard deviation of gage (one appraiser) Width 0.5% 5.15 Sigage Gage repeatability 0.5% 99% of measurements fall in the gage repeatability range Figure 10.1 Gage repeatability. Reproducibility is the appraiser measurement variation expressed as standard deviation. Measurements are taken from the same equipment by more than one appraiser. See Figure 10.2. The repeatability portion of the measurement variance is attributed to the inherent variation of the measurement equipment. One factor that influences this portion of variation is the design of the measurement system itself. In the case of reproducibility, the influential factors are the setting of the work piece (any special loading and unloading), consistency in measurement, and operator training, skill, and knowledge. The measurement system variation is expressed as a ratio of precision to tolerance (P/T). In this case, the value of the divisor "Total variation" is replaced by one-sixth of the tolerance, that is (tolerance) ÷ 6. Most authorities agree that in this situation, %GRR is defined as: (100 × GRR) ÷ (Tolerance/6) Six is used to cover 99.73% of the variation. Some practitioners use 5.15 to cover 99% of the variation. For theoretical purposes, refer to the MSA Reference Manual.1 Standard deviation of gage (more than one appraiser) Appraiser 1 Appraiser 3 Appraiser 2 Figure 10.2 Gage reproducibility. H1493 Ramu_p00i-284.indd 106 7/13/16 5:56 PM Chapter 10 C. Measurement System Analysis (MSA) 107 There are also many inexpensive Microsoft Excel-based macro applications available as off-the-shelf software. Figures 10.3 and 10.4 show the same data analyzed using Minitab statistical software. Sources of measurement variation are shown in Figure 10.5. Gage R&R (X-bar/R) for Measurement Reported by: Tolerance: Misc: Gage name: Date of study: Components of variation 50 Sample range 0 Sample mean Measurement by sample 1 0 0 –2 Gage R&R A Repeat Reproduct Part-to-part 2 R C – R = 0.252 0 LCL = 0 4 5 Sample 7 8 9 10 2 0 –2 Xbar chart by appraiser B 3 Measurement by appraiser UCL = 0.905 A 1 R chart by appraiser 0.5 2 2 % contribution % study var A 2 Appraiser C Appraiser * sample interaction C UCL = 0.362 – X = 0.002 LCL = –0.357 0 –2 Average Percent 0 2 Appraiser A B C –2 1 2 3 4 5 6 7 Sample 8 9 10 Figure 10.3 Example GR&R analysis. Gage R&R study—XBar/R method Source Total gage R&R Repeatability Reproducibility Part-to-part Total variation VarComp 0.09542 0.04315 0.05228 1.21909 1.31451 %Contribution (of VarComp) 7.26 3.28 3.98 92.74 100.00 Source StdDev (SD) Total gage R&R 0.30891 Repeatability 0.20772 Reproducibility 0.22864 Part-to-part 1.10412 Total variation 1.14652 Number of distinct categories = 5 Less than 1% the measurement system is acceptable. Between 1% and 9% the measurement system is acceptable depending on the application, cost of repair, or other factors. Greater than 9% the measurement system is unacceptable and should be improved. Study Var %Study Var (6 * SD) (%SV) 1.85343 26.94 1.24631 18.12 1.37183 19.94 6.62474 96.30 6.87913 100.00 Less than 10% the measurement system is acceptable. Between 10% and 30% the measurement system is acceptable depending on the application, the cost of the measuring device, cost of repair, or other factors. Greater than 30% the measurement system is unacceptable and should be improved. Number of categories 1 Information about conformance versus nonconformance. 2–4 Insensitive controls, coarse estimates of process parameters and capability indices. 5 or more Control charts, process parameters, and capability indices. Figure 10.4 GR&R report using statistical software. H1493 Ramu_p00i-284.indd 107 7/13/16 5:56 PM 108 Part III Measure Phase 100.00% overall variability Part-to-part variability Measurement system variability Variation due to gage Variation due to operators Repeatability Reproducibility Operator by part Reproducibility σ 2 overall = σ 2 part-to-part + σ 2 repeatability + σ 2 operator + σ 2 operator by part Figure 10.5 Sources of measurement variation. Measurement system discrimination is the ability to detect changes in the measured characteristic. If a measurement system's discrimination is inadequate, it may not be possible to accurately measure process variation or quantify characteristic values of individual parts.2 There are minor differences between manual and Minitab software due to rounding errors. The Minitab analysis is more accurate. As mentioned earlier, the measurement system plays a major role in process capability (Cp) assessment. The higher the GR&R, the higher the error in Cp assessment. This increases even more as the capability increases. For example, with an observed Cp of 1 and a GR&R of 50%, the actual Cp is 1.23. By bringing the GR&R down to 10%, Cp is more reflective of the actual process, that is, 1.01. More details on this table, formula, and graphs are available in Concepts for R&R Studies.3 More advanced statistics are available for this type of attribute study involving ranking scores. Examples of this application where objectivity is added to subjective measures are as follows: • Tasting tea, coffee, and wine and assigning a score for taste attributes • Examiners correcting a paper and assigning a score • Fabrics or polished surfaces where the score is assigned by feeling the surface When an independent estimate of process variation is not available, or to determine process direction and continued suitability of the measurement system for process control, the sample parts must be selected from the process and represent the entire production operating range. The variation in sample parts (PV) selected for MSA study is used to calculate the total variation (TV) of the study. The TV index (i.e., %GR&R to TV) is an indicator of process direction and continued suitability of the measurement system for process control. If the sample parts do not represent H1493 Ramu_p00i-284.indd 108 7/13/16 5:56 PM Chapter 10 C. Measurement System Analysis (MSA) 109 the production process, TV must be ignored in the assessment. Ignoring TV does not affect assessments using tolerance (product control) or an independent estimate of process variation (process control). The key point is this: The underlying reason to conduct ongoing MSA of your measurement equipment is to understand the uncertainty of the measurement system; that is, what exactly are you really measuring? Questions 1. Compare accuracy and precision. Describe how these measures are used to certify measurement equipment fitness for use. 2. What specific actions would you recommend for improving the repeatability and reproducibility of the equipment? 3. Explain why it is important to conduct a linearity and bias study for measurement equipment. 4. Identify two or more common misperceptions about MSA study and provide your rationale to counter. 5. What are the applications for variable and attribute GR&R study? Provide examples. H1493 Ramu_p00i-284.indd 109 7/19/16 5:02 PM Part IV Analyze Phase Chapter 11 Chapter 12 Chapter 13 Chapter 14 Chapter 15 A. Process Analysis Tools B. Root Cause Analysis C. Data Analysis D. Correlation and Regression E. Hypothesis Testing 111 H1493 Ramu_p00i-284.indd 111 7/13/16 5:56 PM Chapter 11 A. Process Analysis Tools Define how to use and how SS value analysis can be used to identify and eliminate waste. (Understand) Body of Knowledge IV.A.1 1. Lean Tools SS concepts and value analysis are explained in detail in Chapter 2, "Lean Foundations and Principles." In this section we will look at how these lean tools can be used to identify and eliminate waste. Every process that we can think of can be perfected by pursuing a journey of continual improvement. Whether we are paying for a service provided by a government agency or a product provided by a private company, we as consumers are paying for the waste as well. As an example, I recently received a quote from a software company that explicitly provided allowance for additional hours to make corrections to software code after testing. We have been desensitized to accept waste as normal operating procedure. What can be done to challenge this assumption? If every organization identified and eliminated waste, we would be left with just the value-added activities, which are the bare minimum required for the transformation of input to output. Now, how do you identify waste? Some types are obvious and others are not. Obvious waste in any process is a result of not doing things right the first time (and every time thereafter). In a service industry, wastes include rework, redoing, reinspection of the activity, waiting, delays, and so on. In a manufacturing environment, waste is producing scrap, rework, retest, repair, regrade, reinstall, recall, etc. The manufacturer has to pass the costs of waste on to someone in order to stay in business. This waste is factored into the cost structure and the customer must pay for it. While this is possible for a novel product with no rivals in the market, if a product is a commodity and highly competitive in an open market, the manufacturer cannot always pass on its cost of waste to the customer. The manufacturer will not be competitive. In this case, to reduce operations costs, a few things can happen. The organization can cut the headcount (even letting go those individuals with critical skills), move to low-cost outsourcing locations, use a lower quality of raw materials, or undersell its products to remain afloat. However, all these 112 11 H1493 Ramu_p00i-284.indd 112 7/13/16 5:56 PM Chapter 11 A. Process Analysis Tools 113 Table 11.1 Value-added vs. non-value-added. Value-added Non-value-added Have control Customer willing to pay Eight Wastes No control Not of interest Legal, statutory, regulatory requirements. Select customer requirements. options put the organization at risk. Losing individuals with critical skills and lowering the quality of raw materials results in manufacturing issues and more field returns. Warranty costs will go up and the organization will soon close down due to a bad reputation for quality. Understanding the principles of lean helps organizations to improve the bottom line and result in closing down the organization. Waste can be identified by walking through the process from start to end and looking for any non-value-added activity. This is where value stream analysis is helpful. By closely reviewing every activity as either value-added or non-value-added, one should be able to identify wastes. There are cases where, even if they fall under non-value-added activity, need to be continued out of necessity. For example, there may be inspection or certain testing that is required by a regulatory body, there may be a process step that the customer is willing to pay for even though it does not add value, and so on. The organization has little or no control over these situations. Value-added and non-value-added activities can be summarized in a four-quadrant grid (Table 11.1). Once this simple quadrant is developed, the organization may begin applying lean tools to reduce waste. The first tool to implement is 5S. As explained in Chapter 2, "Lean Foundations and Principles," organizing and standardizing the workplace will help reduce obvious wastes like searching for tools or information, time loss due to accidents, damages during transportation, and so on. Wastes like delays, travel distance, and excess inventory are addressed through tools such as value analysis, one-piece flow, kanban, poka-yoke, SMED, and so on. Define the elements of FMEA and how to use them in order to identify potential failures in a process. (Understand) Body of Knowledge IV.A.2 2. Failure Mode and Effects Analysis (FMEA) The concept of failure mode and effects analysis (FMEA) has been around a long time. In the past, inventors and product developers thought about possible ways a product H1493 Ramu_p00i-284.indd 113 7/13/16 5:56 PM 114 Part IV Analyze Phase that a product could fail during extreme conditions, handling, and usage. They started to provide countermeasures in the design and manufacturing process to prevent these failure modes. FMEA thus started to evolve informally. The military standard MIL-STD-1629A (now obsolete) was a formal document used for FMEA by aerospace and defense applications. This is probably the earliest known FMEA document. The idea behind identifying the failure modes in a system, design, and process started to evolve during the last half century with changes to how risks were weighed, categorized, and calculated. Ford Motor Company used the FMEA approach for design and manufacturing to safeguard against safety- and regulatory-related failure modes. Eventually Ford started to see the benefits of reducing the risks confronting product quality. In 1993, Chrysler, Ford, and General Motors, with input from several technical professionals, created Potential Failure Mode and Effects Analysis, a document that encompassed design and process FMEA. This document became part of the QS-9000 (now ISO/TS 16949) standard's expectations for automotive suppliers. This document, currently in its fourth edition, has been revised with significant input from the SAE J1739 work group and other automotive-product-related organizations. The Automotive Industry Action Group (AIAG) described FMEA as a systematic group of activities intended to: • Recognize and evaluate the potential failure of a product/process and the effects of that failure • Identify actions that could eliminate or reduce the chance of the potential failure occurring • Document the entire process The purpose of FMEA is to understand the opportunities for failure and the impact of risks in a product or process design, prioritize the risks, and take actions to eliminate or reduce the impact of these risks. FMEA is a front-end tool. Successful product/process development requires anticipating failure modes and taking actions to eliminate or reduce failures during deployment and the life cycle. FMEA is not a one-time event; the product/process design team needs to periodically review and update the failure modes. During the early stages of product/process development, the team identifies the risks based on existing data from similar processes, knowledge, and experience. As the product/process is deployed, new unforeseen risks and failures may show up. Hence, reviewing the FMEA on a continual basis ensures sustainable success. It is important to know that the ISO 9001:2015 revision of the standard has multiple references to "risk-based thinking." Annex A indicates that "there is no requirement for formal methods for risk management or a documented risk management process. Organizations can decide whether or not to develop a more extensive risk management methodology than is required by this International Standard, e.g. through the application of other guidance or standards."2 The standard provides flexibility for implementation or organization. Not all processes and businesses require a formal risk management methodology. FMEA may be an excellent way to address and provide evidence of risk-based thinking. H1493 Ramu_p00i-284.indd 114 7/13/16 5:56 PM Chapter 11 A. Process Analysis Tools 115 FMEA needs to be documented and revision controlled and should be part of the existing quality management system (QMS). In a well-designed QMS, FMEA is linked to quality function deployment in the design and process "houses of quality" and linked to control plans in the production house of quality. FMEA is not just confined to manufacturing applications; it has been successfully used in service/transactional processes, software development, and the medical field. Although in principle FMEA is conducted to address the potential failures in product design and process design, it is identified separately as design FMEA and process FMEA. (There is also a system FMEA, but this is beyond the scope of this Body of Knowledge.) Please see the glossary for some of the fundamental terms used in FMEA, such as failure mode, failure effect, failure mechanism, severity, occurrence, detection, and risk priority number. Understanding this terminology is key to performing FMEA assessment. Over the years, the author has reviewed a number of FMEAs from internal processes and suppliers. A common mistake is the mixing up of failure mode and cause failure mode and effect. Refer to the ASQ Quality Progress article "FMEA Minus the Pain" and the related figures in the online version to understand additional pitfalls.3 An evolution of FMEA is FMECA, which includes provisions for assessing and charting the probability of a failure mode occurring versus the severity of the consequences of realizing the failure mode. This is referred to as a criticality analysis—the "C" in FMECA. Steps in Performing FMEA The team approach is most effective for conducting an FMEA, so it is discussed here. Assemble a cross-functional team with diverse knowledge about the process, product, or service and customer needs. Functions often included are design, manufacturing, quality, testing, reliability, maintenance, purchasing (and suppliers), sales, marketing (and customers), and customer service. It is important to have process experts' presence in design FMEA and design experts in process FMEA. For effective interaction, the team is typically five to seven people. If additional experts are needed to provide inputs on safety, regulatory, or legal issues, they are included on the team as subject matter experts. Identify the scope of the FMEA. Is it for concept, system, design, process, or service? What are the boundaries? How detailed should we be? See Table 11.2 for steps in performing an FMEA. Box • Always provide FMEA training to team members before assigning to an FMEA team. • Always use the team approach. • Ask for subject matter expertise if required. • Talk to your customer about how they intend to use the product. • Take time as a team to standardize the scales (for the nature of the business or organization). This helps when comparing the overall risks between FMEAs and helps set up a cutoff score. H1493 Ramu_p00i-284.indd 115 7/19/16 5:02 PM 116 Part IV Analyze Phase Table 11.2 Steps in performing a design or process FMEA. (Continued) Step Design FMEA Process FMEA 1 Review the design Process Use a schematic diagram and a functional block diagram to identify each of the main components of the design and determine the function or functions of those components and interfaces between them. Make sure you are studying all components defined in the scope of the DFMEA. Some components may have more than one function. Use flowcharts to identify the scope and to make sure every team member understands it in detail. It is also recommended that the team perform a walkthrough of the process and understand the process steps firsthand. 2 Brainstorm potential failure modes A potential failure mode represents any manner in which the product component could fail to perform its intended function or functions. A potential failure mode represents any manner in which the process step could fail to perform its intended function or functions. 3 List potential effects of failure The potential effect at interim (local) effects and the end effects are identified. The effect is the ability of the component to perform its intended function due to the failure mode. Both the potential interim (local) effects and end effects are identified. The effect is the impact on the process outcome and product quality due to the failure mode. 4 Assign severity rating (S) The severity rating corresponds to each effect the failure mode can cause. Typically the scale is 1 to 10. Higher severity is rated at the high end of the scale, lower severity at the low end of the scale. 5 List potential causes For every failure mode, list possible cause(s). Use team tools like brainstorming, cause and effect charts, nominal group technique, and multivoting. Where applicable, use a pilot experiment, past data, and expert knowledge. 6 Assign occurrence rating (O) The occurrence rating corresponds to the likelihood or frequency at which the cause can occur. Typically the scale is 1 to 10. Higher occurrence is rated at the high end of the scale, lower occurrence at the low end of the scale. 7 Current controls For each cause, current process controls are identified. Controls can be of different types. They may just detect the failure or prevent the failure from happening. The controls range from work instructions to AQL sampling, SPC, alarms, mistake-proofing fixture, and so on. 8 Assign detection rating (D) The detection rating corresponds to the ability to detect the occurrence of the failure mode. The failure mode has happened but before the customer is affected. Typically the scale is 1 to 10. Higher detectability is rated at the low end of the scale, lower detectability at the high end of the scale. H1493 Ramu_p00i-284.indd 116 7/13/16 5:56 PM Chapter 11 A. Process Analysis Tools 117 Table 11.2 Steps in performing a design or process FMEA. (Continued) Step Design FMEA Process FMEA Calculate RPN Product of severity (S), occurrence (O), and detection (D) (see Glossary for definitions). S × O × D = risk priority number (RPN). Severity × occurrence = criticality is also important in some industries. 10 Develop action plan Action plan may contain tasks to improve the current controls or reduce the frequency of the occurrence of the cause. In order to reduce the severity, the team may have to think of redesigning the product or process. Assign a realistic completion date and responsibility for tasks. 11 Take action Many FMEAs fail apart during this step for lack of management support, conflicting priorities, lack of resources, and lack of team leadership. The actions have to be implemented and results should be validated. Building a prototype, testing the action, and piloting the process in small scale before mass producing are recommended. 12 Recalculate the RPN Bring the team back and objectively recalculate the RPN. Use objective evidence like customer feedback, reliability tests, warranty return rate, yield tracking, and so on, to reassess the score. 13 Periodically review and update new risks Carefully evaluate customer feedback, warranty analysis, internal nonconformance reports, ongoing reliability test reports, and so on, to explore new risks and update the FMEA. Keep the FMEA as a living document. • Brainstorm all possible failure modes (be sure to include those that might happen only occasionally). • When two risks have the same overall score, the risk with the higher severity rating is escalated. • Complete the action and reassess the risks as a team. • Update the FMEA with new learned risks. Don'ts • Don't copy the - severity-occurrence-detection scales from another industry or organization. The description of the scale levels and impact may be different from that of your organization. • Don't force-fit risks into a 1–10 scale. If there are not many levels of severity, occurrence, and detection in your industry, try a 1–5 scale. • Don't create customized scales within the organization unless it is absolutely essential. (Standardization of scales within the organization or product family/technology is helpful when comparing risks.) • Don't fight over small ratings differences, such as between 4 and 5 or 6 and 7. Analyze the impact thoroughly if the team is divided by 4 to 7 ratings. H1493 Ramu_p00i-284.indd 117 7/19/16 5:02 PM 118 Part IV Analyze Phase Table 11.2 ... (Continued) Don'ts • Don't spend time on some rating points, for example, 4 and 7 or 7 and 10. Don't average scales from participants for team harmony. This may affect the outcome of the risk assessment. • Don't get hung up on the numbers; the objective is to create a risk-reduced product and/or service. • Don't perform FMEA just to comply with procedures or standards. FMEA is a business risk management tool. It has to be used with commitment to make it work. Once the initial risk priority number (RPN) scores are tabulated, the team may decide on a cutoff score. For most organizations, the cutoff score is standardized. The cutoff score of one organization may not be directly applicable to another. Too low a cutoff score can result in spending lots of resources to eliminate or reduce several risks. Too high a cutoff score can result in not addressing important risks. Management needs to review and agree on a score. One of the challenges of RPN prioritization is the risks with high severity and low probability of occurrence. These risks, if they happen, could be disastrous to the organization. It is very common for the team and management to discount risks that are abstract and rare. However, the team should know that these risks can happen. The Fukushima nuclear disaster is a good example. While the probability of an earthquake triggering a tsunami is rare, it did happen. The nuclear facility reportedly was unprepared for an event of this magnitude. The effect was known to all of us watching the news from Japan. Figures 11.1 through 11.3 show various FMEA implementation tools and examples. Note: FMEA is a powerful tool, but it requires in-depth knowledge to be successfully executed. It is recommended that guidance be sought from others who have performed an FMEA. Successful FMEA implementation requires leadership and management commitment. Here is one of the few tools that can test the patience of team members. Instead of tackling FMEA for multiple process steps for the product in several Risk ID Risk 7 Jan 17 Feb 17 Mar 17 Apr 17 May 17 Jun 17 Planned Actual Risk 1 Planned Actual Risk 3 Planned Actual Risk 9 Planned Actual Figure 11.1 A typical risk action plan Gantt chart. H1493 Ramu_p00i-284.indd 118 7/13/16 5:56 PM Chapter 11 A. Process Analysis Tools 119 Before taking action After taking action ID Risk ID S O D Risk ID S O D Recalc: RPN Risk 7 8 280 Risk 7 5 5 3 75 Risk 1 8 8 4 256 Risk 1 8 4 3 96 Risk 3 5 5 7 175 Risk 5 3 5 4 60 Risk 9 7 5 4 140 Risk 9 7 5 4 140 Risk 4 4 4 128 Risk 5 5 3 3 72 Risk 2 7 4 3 84 Risk 6 5 3 5 75 Risk 6 3 7 2 42 Risk 6 4 3 3 72 Risk 2 9 5 4 180 Risk 3 5 3 2 30 Risk 8 5 3 3 30 Risk 8 Risk 10 3 3 2 18 Risk 10 3 3 2 27 Before taking action After taking action RPN total with initial RPN total 280 RPN 256 RPN 200 RPN 150 RPN 100 RPN 50 RPN 0 Risk Risk 7 Risk 1 Risk 3 Risk 9 Risk 4 Risk 5 Risk 2 Risk 6 Risk 8 Risk 10 Before taking action After taking action Figure 11.2 Example of RPN tracking. XYZ Corporation Management Review Report—FMEA Implementation Progress No. of FMEAs risks over cutoff 100 = 245 Total no. of FMEA risks identified = 550 No. of risks to be reduced below cutoff by end of quarter = 60 Organizations review their FMEA status for every process and risk. Q1, Q2, Q3, and Q4. Figure 11.3 A typical top-level management review report for FMEA progress. H1493 Ramu_p00i-284.indd 119 7/13/16 5:56 PM 120 Part IV Analyze Phase meetings, try splitting the process into major process blocks and perform FMEA by block in one sitting. Also, maintaining a good FMEA database will significantly reduce the time spent on successive FMEAs. Questions 1. Choose from a bakery shop, bank, car repair shop, or doctor's office and explain how 5S implementation could be beneficial in identifying and eliminating waste. 2. Create a value analysis of the business selected in question #1, and identify the wastes in one of the categories in Table 11.1. 3. What are the main pitfalls to watch for when conducting an FMEA? What are your countermeasures to address these pitfalls at the planning stage of the FMEA? 4. What is the purpose of setting a risk priority number (RPN) cutoff in an FMEA? What is the downside of making risk prioritization decisions based only on the RPN? 5. Develop a process FMEA for every step of either a value stream map or a process flowchart. H1493 Ramu_p00i-284.indd 120 7/13/16 5:56 PM Chapter 12 B. Root Cause Analysis Define and describe the purpose of root cause analysis, recognize the issues involved in identifying a root cause, and use various tools (e.g., 5 whys, Pareto charts, fault tree analysis, cause and effect diagrams) to resolve chronic problems. (Analyze) Body of Knowledge IV.B Root cause analysis (RCA) is an important step in problem solving. Once we follow the PDCA approach or DMAIC methodology for problem solving or improvement, RCA is required. Why try to uncover the root cause? Many causes that result in problems that confront us are not obvious. • There are apparent causes and root causes. Addressing the apparent causes doesn't eliminate the problem. Problems reoccur, resulting in more time and effort to address the same problems. • Root causes reside deeper. How deep? This depends on the complexity of the problem. There may be more than one cause of the problem experienced. Different causes may have different contributions to the manifestation of the problem. Apparent causes are those that appear in the first layer of the RCA: Why didn't the product work? — Apparent cause: Damage during transport — Root cause: Packaging not designed to withstand shock and vibration anticipated during the transport Why does the process have scrap products? — Apparent cause: Process control (inspection) did not work — Root cause: Process is not capable Why did the operator have an accident? — Apparent cause: Operator did not follow the safety instructions — Root cause: Safety guard not error proofed to stop equipment In these cases, it is normal human tendency to jump on the apparent causes and superficially address them. RCA requires knowledge and experience to diagnose the effected process. Resource constraint is required to design a system that 121 12 H1493 Ramu_p00i-284.indd 121 7/13/16 5:56 PM 122 Part IV Analyze Phase For an effective RCA, it is important to allow the time needed for a process, to allow root cause to emerge. Problem solving is often influenced by a sense of urgency. Patience is allowing the process to work and not skipping steps to save time. There are many problem-solving tools available in the quality toolbox, brainstorming, seven quality tools, why-why analysis (5 whys), and is-is not analysis are just a few of the tools. 5 Whys or Why-Why Analysis 5 whys analysis is an easy-to-use approach for arriving at a root cause. It is widely used because of its simplicity. No special training or skill is required. All you need is the persistence to ask "Why?" every time you get an answer and keep going until you reach the root cause. If you have ever observed a five-year-old child, you know they are very inquisitive. At this age, the child wants to know more by asking "Why?" There are times we as adults run out of answers. So if we all started by asking questions, when did we stop asking? As we age, we are influenced by our experiences and environment. We make up our minds as to the answer for every question and continue to live with assumptions. We hardly ever challenge our assumptions. The 5 whys tool forces us to keep asking questions. Many quality professionals get hung up on the number 5 in "5 whys" and force themselves to ask why five times. But depending on the complexity of the issue, one might arrive at the root cause at the third or seventh why or even the ninth why. "5" whys is simply a guideline and should not be taken literally. To avoid this misunderstanding, organizations have begun to call this tool "why-why analysis." There is always a question from users as to when to stop asking why. If you stop at the second or third why, the cause may still be shallow. If you keep going to a seventh or eighth why, the cause gets very broad, like "organizational culture" or "business situation." This is not quite actionable by the RCA team. The ideal point at which to stop is where the root cause is specific and actionable and the problem solver or organization has no control to act on the subsequent why. Let's look at an example from the Toyota website:1 1. "Why did the robot stop?" The circuit has overloaded, causing a fuse to blow. 2. "Why is the circuit overloaded?" There was insufficient lubrication on the bearings, so they locked up. 3. "Why was there insufficient lubrication on the bearings?" The oil pump on the robot is not circulating sufficient oil. 4. "Why is the pump not circulating sufficient oil?" The pump intake is clogged with metal shavings. 5. "Why is the intake clogged with metal shavings?" Because there is no filter on the pump. H1493 Ramu_p00i-284.indd 122 7/13/16 5:56 PM Chapter 12 B. Root Cause Analysis 123 In this example, if the manufacturing quality practitioner had stopped at the first why, the organization would have thought that the fuse was the root cause and thus would have kept a huge number of fuses as a maintenance spare part inventory. If the practitioner had stopped at the second why, the operator would have been advised to keep pouring more lubrication. This would have resulted in spillage on the floor, which could have led to an accident. In the fifth why, identifying the lack of a filter as the root cause is sufficient because the use of a filter that is periodically replaced during preventive maintenance will prevent the robot from stopping. To understand the system-level root cause, we should continue asking why. 1. "Why wasn't the filter on the pump replaced?" Maintenance technician forgot to replace during the preventive maintenance. 2. "Why did the maintenance technician forget to replace?" There is no process for routine preventive maintenance. I would stop at this point to ensure that there is a defined, documented, and fully deployed effective maintenance process that not only ensures replacement of the filter but also prevents any errors in the future. Once a root cause has been identified in the 5 whys/why-why analysis, it is important to verify that the root cause can indeed address the problem symptom. If you have the ability to turn the root cause on and off to verify prevention and re-creation of the problem, this is an effective way to confirm the root cause. However, this is not always practical. Some root causes are not easy to re-create, and even if we could re-create them, it could cause significant undesirable effects on the customer. In these scenarios, practitioners are advised to be creative in verification, for example, using a software simulation or equivalent method. Finally, verify recurrence of the events. Complaints from the customer is a reactive approach for verifying whether the root cause has been correctly identified and the corresponding corrective action is effective. Process Mapping ISO 9000:2015 (Quality management systems—Fundamentals and vocabulary) defines a process as a set of interrelated or interacting activities that transforms inputs into outputs. A process flowchart is a helpful tool during problem investigation. A process is easily understood by visually presenting the process using common flowcharting shapes and symbols. This method depicts processes, both simple and complex, more effectively than extensive written descriptions. Organizations often send their process information in the form of process map documentation to their suppliers and customers for contractual reasons. In my experience, I have seen process maps and flowcharts used extensively in Japanese organizations. They call it "QC process flow." It is typically an end-to-end process flow starting from contract review and approval through delivery of goods. Let us clarify upfront that process mapping is a process by itself to map a process, and a flowchart is a tool used to conduct mapping. Practitioners often use process mapping and process flowcharting interchangeably. Some authors try to H1493 Ramu_p00i-284.indd 123 7/13/16 5:56 PM 124 Part IV Analyze Phase distinguish a process map as a flowchart with additional process-related information as follows. Flowcharts show each step in a process, including inputs, decision points, and outputs. Process maps usually contain additional information about the steps, including costs, setup time, cycle time, inventory, types of defects that can occur, probability of defects, and other relevant information that helps in understanding the process better. The flowchart is typically presented on the left side of the page, continuously running for multiple pages in one column, and the space on the right is used to describe the process, responsibilities, control points, metrics, and so on. Using consistent mapping icons helps different individuals interpret the maps in the same way. International standard ISO 5807:1985 Information processing—Documentation symbols and conventions for data, program and system flowcharts, program network charts and system resources charts helps accomplish just that. Process mapping is often the first step in improving a process. Risk analysis tools such as process failure mode and effects analysis (PFMEA) start with process mapping. Value stream mapping (VSM), used in lean enterprise projects, is also a type of process mapping but uses different mapping icons. In addition, VSM focuses more on measurement of the flow of material and information and the utilization of resources. Process maps and flowcharts enable a broader perspective of potential problems and opportunities for process improvement. Teams using these tools get a better understanding of process steps and sequence of operations. Figure 12.1 shows some of the most frequently used process mapping symbols from the international standard ISO 5807:1985. Figure 12.2 gives a basic flowchart example. There are a number of mapping icons available within most office productivity software applications. Symbolizes one step in the process; the step is written inside the box. Usually, only one arrow goes out of the box. Direction of flow from one step or decision to another. Decision box. The question is written in the diamond. More than one arrow goes out of the diamond, each one showing the direction the process takes for a given answer to the question. (Often the answers are yes and no.) Delay or wait Link to another page or another flowchart. The same symbol on the other page indicates that the flow continues there. Input or output Preparation Document Manual operation Alternate symbols for start and end points Figure 12.1 Symbols commonly used in flowcharts and process maps. Source: N. R. Tague, The Quality Toolbox, 2nd ed. (Milwaukee, WI: ASQ Quality Press, 2005): 262. H1493 Ramu_p00i-284.indd 124 7/13/16 5:56 PM Chapter 12 B. Root Cause Analysis 125 Start Customer identifies a product failure during use No replacement. Discard according to environmental guidelines No Customer verifies warranty conditions for replacement Yes Customer fills out warranty replacement form Attach the form with the defective product and send to warranty handling Customer support clerk processes the application Customer support staff sends a letter explaining the reason for disqualifying warranty claim Send the defective product for failure investigation No Customer support staff verifies warranty conditions for replacement Yes Place an order for product replacement A Warehouse clerk receives the order Physically retrieves a new product from the shelf Ships to the customer requesting replacement Customer receives replacement Figure 12.2 Basic flowchart for replacement of a product under warranty. H1493 Ramu_p00i-284.indd 125 7/13/16 5:56 PM 126 Part IV Analyze Phase Customer Customer support Warehouse Customer fills out warranty replacement form Customer support clerk processes the application Warehouse clerk receives the order Attach the form with the defective product Place an order for product replacement Physically retrieves a new product from the shelf Send the defective product for failure investigation Ships to the customer requesting replacement Figure 12.3 Cross-functional or swim lane flowchart. Process mapping involving multiple departments or functions is more easily understood using "swim lane" mapping. Imagine different departments, functions, or stakeholders involved in a process as being in different swim lanes either horizontally or vertically. A swim lane process map is similar to a typical process map except that the process blocks are aligned with the lane of the department or function that performs a given process step. Let's re-map the example shown in Figure 12.2 using the swim lane flowchart approach. For simplicity, the decision loops from the previous chart have been taken out. In a real business scenario, the swim lane flowchart in Figure 12.3 contains all the components presented in a basic flowchart. It uses the same flowchart symbols and guidelines shown in Figure 12.1 for creating the chart. Creating a Flowchart (Process Map or Process Flow Diagram) When creating a flowchart, we are creating a picture of the actual steps in a process or system as it actually operates or is supposed to operate. Given the old adage that a picture is worth a thousand words, this tool allows us to communicate using standard symbols. The flowchart is very useful when looking at a process we want to improve. A flowchart should be developed for a new process before the process is implemented. However, there may be situations where you are using a flowchart to document an already-existing process. We can follow some basic steps to create the flowchart: 1. Create the boundaries of the process for which we are creating the flowchart. These might be the inputs and outputs of the process or the suppliers and customers of the process. H1493 Ramu_p00i-284.indd 126 7/13/16 5:56 PM Chapter 12 B. Root Cause Analysis 127 2. Determine the various steps in the process through team brainstorming or walking the process (for documenting an already-existing process). At this point, we are not worried about sequence, only collecting all of the steps. 3. Build the sequence of the process, putting everything into the appropriate order. We have to make sure we understand that some process steps happen in parallel, and the chart should reflect this accordingly. There are also alternative paths identified in some charts. 4. Draw the flowchart using the appropriate mapping symbols. 5. Verify that the flowchart is complete and appropriate for the given operation (for a new chart). Verify that the flowchart fully matches with the process (for an already-established process). This is especially important if more than one group is working on a large process. Overlaps or deletions may occur between processes. Hence, this activity is best performed as a team. Flowcharts are a good graphical tool for both monitoring process changes over time and conducting training of new operators or supervisors. By referencing the flowcharts on a regular basis, we will be able to use them as visual standards to help ensure that things run as they are supposed to. Note that if a change is made to the process, it is important to update the flowchart to reflect the change. Regular audits may be done in a given area for any number of reasons (safety, quality, environmental, and so on), so having the flowcharts readily available helps everyone involved in verifying compliance. Process mapping can help reveal redundancy in the process, non-value-added steps, and unnecessary complexities. Process mapping can be used to identify and eliminate those process issues and improve the sense. The wrong choice may lead to meaningless results. Correlation Coefficient The correlation coefficient r provides both the strength and the direction of the relationship between the independent and dependent variables. Values of r range between –1.0 and +1.0. When r is positive, the relationship between x and y is positive (Figure 14.1a), and when r is negative, the relationship is negative (Figure 14.1b). A correlation coefficient close to zero is evidence that there is no relationship between x and y (Figure 14.1c). Figure 14.d indicates a nonlinear relationship between variables. The strength of the relationship between x and y is measured by how close the correlation coefficient is to +1.0 or –1.0. 10 10 8 8 6 6 y 12 y 12 4 4 2 2 0 0 5 x 10 0 15 0 a. Strong positive correlation 10 8 8 6 6 y 10 y 12 4 4 2 2 0 5 x 10 15 x 10 15 b. Strong negative correlation 12 0 5 0 0 c. No correlation 5 x 10 15 d. Nonlinear relationship Figure 14.1 The four types of correlations in scatter plots. H1493 Ramu_p00i-284.indd 144 7/19/16 5:02 PM Chapter 14 D. Correlation and Regression 145 We can calculate the correlation coefficient using the following formula: ΣxΣy N r= 2 ⎛ ⎛ 2 (Σx) ⎞⎛ Σ y)2 ⎞ 2 Σ x − y Σ − ⎜ ⎟⎜ N ⎟⎟⎜ N ⎟⎜ Σ xy − Using Microsoft Excel to Calculate Correlation Coefficients You can use Microsoft Excel to calculate correlation coefficients. Use the CORREL function, which has the following characteristics: CORREL(array1, array2) where array1 = the range of data for the first variable array2 = the range of data for the second variable Figure 14.2 shows the CORREL function being used to calculate the correlation coefficient for the weight loss example. Cell C8 contains the Microsoft Excel formula =CORREL(A2:A7,B2:B7) with the result being 0.972717. Figure 14.2 CORREL function in Microsoft Excel. H1493 Ramu_p00i-284.indd 145 7/13/16 5:56 PM 146 Part IV Analyze Phase 2. Regression Describe how regression analysis is used to predict outcomes. (Understand) Body of Knowledge IV.D.2 Simple Regression Simple regression is used to describe a straight line that best fits a series of ordered pairs (x,y). An equation for a straight line, known as a linear equation, takes the form: yˆ = a + bx where value of y, given a value of x yˆ == aˆthe + bˆpredicted x x = the independent variable a = the y-intercept for the straight line b = the slope of the straight line The Least Squares Method The least squares method is a mathematical procedure to identify the linear equation that best fits a set of ordered pairs by finding values for a (the y-intercept) and b (the slope). The goal of this method is to minimize the total squared error between the values of y and yˆ .= aˆ + bˆx If we denote the predicted value of y obtained from the fitted line as yˆ ,=the aˆ + bˆx predicted equation is: yˆ = aˆ + bˆx where yˆ = aˆ +and bˆx bˆ represent estimates of true a and b. Since we need to choose the b est-fitting line, we need to define what we mean by "best." For the purpose of getting the best-fitting criteria, the principle of least squares is employed; that is, one has to choose the best-fitting line, the line that minimizes the sum of squares of the deviations of the observed values of y from those predicted. Let's look at an example of how the regression statistical method could be used to predict outcomes. H1493 Ramu_p00i-284.indd 146 7/13/16 5:56 PM Chapter 14 D. Correlation and Regression 147 Using Microsoft Excel for Simple Regression 1. Sort the data from Table 14.2 into columns A and B in a blank Microsoft Excel spreadsheet. 2. Under the Tools menu, select Data Analysis. (If Data Analysis does not automatically appear, you may have to go to the Options menu and check Data Analysis.) 3. From the Data Analysis dialog box, select Regression, as shown in Figure 14.3, and click OK. 4. Set up the Regression dialog box as shown in Figure 14.4; enter input x and y range. 5. Click OK, which brings up the results shown in Figure 14.5. Table 14.2 Temperature viscosity experiment. Temperature (°C) Viscosity (centipoise) 10 2 15 3 20 5 15 4 Figure 14.3 Regression dialog box. H1493 Ramu_p00i-284.indd 147 7/13/16 5:56 PM 148 Part IV Analyze Phase Figure 14.4 Regression data analysis. Figure 14.5 Simple regression results. H1493 Ramu_p00i-284.indd 148 7/13/16 5:56 PM Chapter 14 D. Correlation and Regression 149 Six Sigma professionals find the linear regression tool helpful for making an estimate. This analysis can be effectively used during the Measure, Analyze, and Improve phases. In the Measure phase, this tool is used during the MSA-linearity study. In the Analyze phase, this tool is used for exploring relationships between variables. In the Improve phase, this tool can be used to estimate gains after the projected improvement. Questions 1. Provide examples of correlation and causation. 2. The data shown in the following table were collected by surveying 100 employees with five years' experience. Find the correlation relationship for the data set using Microsoft Excel. Calculate the correlation coefficient. Identify whether the relationship is positive or negative and whether it is strong. Years of schooling Total annual salary 10 $32K 12 $33K 15 $45K 17 $60K 3. Use the regression method to calculate potential revenue in $K if the organization budgets $30K on quality improvement activities. Money spent on quality improvement ($K) Revenue ($K) 5 1000 10 1500 15 3000 20 3200 4. Explain your course of action if you find either no correlation or a nonlinear correlation among the data set. 5. Explain the application of the discussed methods in an improvement project or problem solving. At what stage could correlation and regression be used effectively? H1493 Ramu_p00i-284.indd 149 7/13/16 5:56 PM Chapter 15 E. Hypothesis Testing Define and distinguish between hypothesis terms (i.e., null and alternative, type I and type II error, p-value and power). (Understand) Body of Knowledge IV.E A hypothesis is an assumption about a population parameter, for example: The average adult drinks 1.7 cups of coffee per day No more than 2% of our products are defective Average transaction time at a call center is 5 minutes These statements about a population may or may not be true. The purpose of hypothesis testing is to make a statistical conclusion about accepting or not accepting such statements. The Null and Alternative Hypotheses All hypothesis tests have both a null hypothesis and an alternative hypothesis. A null hypothesis, denoted by H0, represents the status quo and involves stating the belief that the mean of the population is ≥, =, or ≤ a specific value. The null hypothesis is believed to be true unless there is overwhelming evidence to the contrary. It is similar to a court trial. The hypothesis is that the defendant is not guilty until proven guilty. However, the term "innocent" does not apply to a null hypothesis. A null hypothesis can only be rejected or fail to be rejected; it cannot be accepted because of a lack of evidence to reject it. If the means of two populations are different, the null hypothesis of equality can be rejected if enough data are collected. When rejecting the null hypothesis, the alternative hypothesis must be considered. For example, the average weight of a component is six grams. The null hypothesis would be stated as: H0: μ = 6.0, H0: μ ≤ 6.0, H0: μ ≥ 6.0 150 15 H1493 Ramu_p00i-284.indd 150 7/13/16 5:56 PM Chapter 15 E. Hypothesis Testing 151 The alternative hypothesis, denoted by H1, represents the opposite of the null hypothesis and holds true if the null hypothesis is found to be false. The alternative hypothesis always states that the mean of the population is a specific value. The alternative hypothesis would be stated as H1: μ ≠ 6.0, H1: μ > 6.0, H1: μ < 6.0 In order to test a null hypothesis, a calculation must be made from sample information. This calculated value is called a test statistic and is compared with an appropriate "critical value." A decision can then be made to reject or not reject the null hypothesis. The "critical value" is obtained from the t distribution table in Appendix H against a chosen level of significance. The typical levels of significance are 1%, 5%, and 10% (both tails). Types of Errors Two types of errors are possible when formulating a conclusion regarding population based on observations from a small sample: Type I error: This type of error results when the null hypothesis is rejected when it is actually true. For example, incoming products are good but were labeled defective. This type of error is also called α (alpha) and referred to as the producer's risk (for sampling). Type II error: This type of error results when the null hypothesis is not rejected when it actually should have been rejected. For example, incoming products are defective but were labeled good. This type of error is also called β (beta) and referred to as the consumer's risk (for sampling). The types of errors are shown in Table 15.1. The hypothesis table has four quadrants. Rejecting the null hypothesis when the outcome is false is a "correct" judgment. Similarly, failing to reject the null hypothesis when it is true is also a "correct" judgment. However, judgment error occurs when the null hypothesis is rejected when the outcome is true and when the null hypothesis fails to be rejected when the outcome is false. These are the errors explained as Type I and Type II and presented in the table. One-Tail Test Any type of hypothesis test has an associated risk, and it is generally the α risk (Type I error, which rejects the null hypothesis when it is true). The level of this Table 15.1 Error matrix. False True Reject H0 p = 1 – β, correct outcome p = 1 – α, Type I error Do not reject H0 p = β, Type II error p = 1 – α, correct outcome Note: p = 1 – β is also called power. Higher power is better in a hypothesis test. H1493 Ramu_p00i-284.indd 151 7/19/16 5:02 PM 152 Part IV Analyze Phase (a) Right-tailed test Entire α = 5% μ0 = 20% (b) Left-tailed test Entire α = 5% μ0 = 20% Figure 15.1 One-tail test: (a) right-tailed test and (b) left-tailed test. α risk determines the level of confidence (1 – α) that we have in the conclusion. This risk factor is used to determine the critical value of the test statistic, which is compared with a calculated value. If a null hypothesis is established to test whether a sample value is smaller or larger than a population value, then the entire α risk is placed on one end of a distribution curve. This constitutes a - one-tail test (Figure 15.1). H0: level ≥ 20%, H1: level < 20% Example A golf ball manufacturer claims its new golf ball will increase the driving distance off the tee by more than 20 yards. The hypothesis is set up as follows: H0: μ ≤ 20, H1: μ > 20 In Figure 15.1, there is only one rejection region, which is the shaded area on the distribution. We follow the same procedure outlined below for the two-tail test and H1493 Ramu_p00i-284.indd 152 7/13/16 5:56 PM Chapter 15 E. Hypothesis Testing 153 plot the sample mean, which represents the average increase in distance from the tee with the new golf ball. Two possible scenarios exist: • If the sample mean falls within the white region, we do not reject H0. That is, we do not have enough evidence to support H1, the alternative hypothesis, which states that the new golf ball will increase distance off the tee by more than 20 yards. • If the sample mean falls in the rejection region, we reject H0. That is, we have enough evidence to support H1, which confirms the claim that the new golf ball will increase distance off the tee by more than 20 yards. Note: For a one-tail hypothesis test, the rejection region will always be consistent with the direction of the inequality for H1. For H1: μ > 20, the rejection region will be in the right tail of the sampling distribution. For H1: μ < 20, the rejection region will be in the left tail. Two-Tail Test If a null hypothesis is established to test whether a population shift has occurred in either direction, then a two-tail test is required. In other words, a two-tail hypothesis test is used whenever the alternative hypothesis is expressed as ≠. The allowable α error is generally divided into two equal parts (see Figure 15.2). p-Value Statistical significance is used to evaluate whether the decision made in a hypothesis test is valid. We often encounter situations like comparing "before and after" improvements, test equipment, service quality level, defects from two processes, and so on. Statistical significance is expressed by a p-value. Standard statistical H0 : Levels are equal H1 : Levels are not equal α /2 = .025 α /2 = .025 –1.96 0 μ0 +1.96 Figure 15.2 Two-tail test. H1493 Ramu_p00i-284.indd 153 7/13/16 5:56 PM 154 Part IV Analyze Phase references define p-value as "the probability of obtaining a test statistic result at least as extreme or as close to the one that was actually observed, assuming that the null hypothesis is true."1 If the calculated p-value is greater than the significance level considered (often 1% or 5%), then the p-value is not significant enough to conclude that the null hypothesis is true. As for practical significance, a difference between two data sets may be statistically significant, but the question is, is it practically significant? As an example, the difference between two process defect levels is statistically significant. The difference is 0.5%. The customer is allowing a defect level of 3% for this process since the step is not critical. Similarly, a difference between two pieces of test equipment of up to 50 microns may be practically acceptable, while statistical significance may require a difference of 20 microns to determine that the null hypothesis is true. It is important to ensure that the sample size calculated for the hypothesis testing is statistically adequate. Without a statistically significant sample size, the analysis may reveal a difference between data sets, but the probability of correctly detecting such a difference may be low due to low power in the experiment. This may lead to making incorrect decisions and taking risks that cost the organization. By conducting statistical analysis, even if the sample size is inadequate to conclude the difference, we can estimate power in the decision and inform stakeholders of risks involved in the lower-than-desired power. What Is a Desired Power? A power of 0.8 and above is typically required for making a conclusion. A power of 0.9 or more may be required in some situations based on the risk to the organization. A power of 0.8 means an experiment with the current sample size has an 80% likelihood of identifying a significant difference (more than 1% defectives) when one truly exists, and a 20% likelihood it will incorrectly identify a significant difference when the difference does not exist. When to Calculate a Statistically Significant Sample Size Statistically significant sample sizes using power and sample size are calculated before you design and run an experiment or improvement or after you perform an experiment or improvement. How to Calculate a Statistically Significant Sample Size Inputs for calculating a statistically significant sample size depend on: σ — The variability in the population (or experimental variability). As σ decreases, power increases. δ— The size of the effect (difference to detect). As the size of the effect increases, power increases. α— The probability of a type I error (also called the level of significance). β— When H0 is false and you fail to reject it, you make a type II error. The probability (p) of making a type II error is called beta. H1493 Ramu_p00i-284.indd 154 7/13/16 5:56 PM Chapter 15 E. Hypothesis Testing 155 1.0 Power curve for one-sample Z-test Sample size 0.9 6 Power 0.8 Assumptions 0.05 StDev 0.03 Alternative ≠ α 0.6 Position only. Draw Figure 17.3 0.4 0.2 0.0 –0.050 –0.025 0.000 Difference 0.025 0.04 0.050 Figure 15.3 Power curve. From Figure 15.3, a process with standard deviation 0.03 can detect a difference in mean value of 0.04 with 0.9 power if six samples were used. Questions 1. The null hypothesis for the average defective rate at the final inspection is less than or equal to 100 DPPM. Write the null and alternative hypotheses statements. 2. The null hypothesis for the waiting time at a popular restaurant during the busy hours is 30 minutes. Write the null and alternative hypotheses statements. 3. If the p-value of a hypothesis test performed is 0.045, would you reject or fail to reject the null hypothesis at a significance level of 5%? For extra credit, explain the risk in this decision and what additional information you might seek to make sure you provide a full picture to your management. 4. When would you provide a high level of protection for producer and consumer risks? Give an example for both scenarios. 5. The power of your experiment performed at the Improve phase is 0.6. Explain to the class what this means. H1493 Ramu_p00i-284.indd 155 7/13/16 5:56 PM Part V Improve and Control Phases Chapter 16 Chapter 17 A. Improvement Techniques B. Control Tools and Documentation 157 H1493 Ramu_p00i-284.indd 157 7/13/16 5:56 PM Chapter 16 A. Improvement Techniques Define and distinguish between these two methods and describe how they can be used to make improvements to any process in an organization (Understand) Body of Knowledge V.A.1 1. Kaizen and Kaizen Blitz Kaizen is a Japanese term meaning "change for improvement," or improving processes through small, incremental steps (Figure 16.1). It is expressed by two characters in Japanese as "change" and "good." This is a key fundamental. Many times organizations make changes with the intention of making something good, but due to either poor conception or poor deployment, the change does not result in something good. Even if the change had a positive outcome, it may not be sustainable or it may create a new problem in another area of business. Kaizen programs are managed at the gemba (workplace), where the process happens. Kaizen improvements are managed by the employees who manage the process. They are empowered to make changes. At the same time, the changes are carefully reviewed by process owners to ensure the changes do not create new issues downstream. Breakthrough improvement is referred to by another Japanese term, kaikaku. Kaikaku is referred to in North America as a kaizen event or kaizen blitz. Hence, many practitioners are often confused by the interchangeable usage of "kaizen" and "kaizen event." In lean implementation, kaizen events are used to provide Kai Zen Change Good Figure 16.1 Meaning of "kaizen." 158 16 H1493 Ramu_p00i-284.indd 158 7/13/16 5:56 PM Chapter 16 A. Improvement Techniques 159 quicker implementation results. Kaizen events are conducted by assembling a cross-functional team for three to five days and reviewing all possible options for improvement in a breakthrough effort. Management support is required for such initiatives. If the employees can't afford to take three to five days to improve a process constraint, then either the problem is unimportant or the organization requires more fundamental cultural adjustment before implementing lean. Humans are wired to improve incrementally through continuous improvement. Most industrial development today has evolved over thousands of years of incrementally improving a situation thought to be a constraint in meeting the human needs at that point in time. The evolution of tools, utensils, clothing, and shelter is a great example of such incremental improvements. If we can exploit the natural skill of humans to think through the constraints, find alternate solutions, and incrementally improve products and processes, we can accomplish improved quality, productivity, safety, cost reduction, customer satisfaction, and overall societal quality of life. Incremental improvement, or kaizen, is achieved by the people who work on the process every day. By challenging themselves to improve quality and productivity without incurring significant capital investment, employees provide small, steady improvements in their work. Kaizen from day-to-day work is submitted by employees for review and approval. These small, gradual improvements are piloted and implemented across the organization. There needs to be management support and recognition of the efforts for kaizen improvements. Management needs to empower the employees to propose and make incremental changes to the products and processes. If the system bureaucracy gets in the way, employee creativity will be affected and the free flow of ideas will be stopped. If management does not recognize the employees' effort, kaizen initiatives will not succeed. Kaizen improvements need to be managed through an infrastructure. Improvement implemented ad hoc can cause more harm than good. A process for managing the kaizen improvements needs to be put in place. This process should allow employees to make proposals for kaizen improvements and describe benefits that could be realized. This process should also go through evaluation of the proposed improvements for any undesired or unintended impacts due to implementation of the improvement. This level of due diligence is obviously required to account for the changes and reward the useful improvements. At the same time, the improvements must be visible so that the organization can manage any risks due to changes. Incremental improvements also have limitations. After these improvements are exhausted, the management has to think of breakthrough improvement strategies. Kaizen improvement management requires the following: • A documented process • A form to submit the improvement proposal for review • Review team • Approvers • Implementation and follow-up of the improvement for effectiveness • Reward and recognition system • Organization of the changes made by product and process H1493 Ramu_p00i-284.indd 159 7/13/16 5:56 PM 160 Part V Improve and Control Phases Additionally, the kaizen improvement infrastructure has to be supported by providing training to employees on continuous improvement methodology, the seven quality tools, and problem solving. Management is also encouraged to create dashboards of the improvements made to products and processes and publicize overall monetary benefits to the organization to motivate employees. Bulletin boards can be used to display pictures of the improvement for additional encouragement. Successful organizations also have dashboard or key process indicator metrics for incremental continuous improvements (e.g., number of improvements/ employee/year). Process owners begin planning for a kaizen event, or kaizen blitz, four weeks ahead of the actual event. The team leader (typically the process owner) starts collecting information related to the process: flowcharts, product specifications, customer requirements, process requirements, equipment information, tools, process performance, dashboards, inventory, and so on. A c ross-functional team related to the process is put together. If required, a "sensei" (teacher or mentor) will be hired. On the first day of the kaizen event, the team is trained on lean enterprise basics and other tools required for the improvement project, like root cause analysis. On the second and third days, the team walks the gemba (workplace), mapping the current value stream or current situation and identifying opportunities for improvement. On days four and five the team creates future value stream maps and starts making improvements. If the process is less complex, the improvements are made during the kaizen event, and sustaining the improved process starts after day five. If the process is rather complex and improvements are likely to take longer than the event duration, the improvements are managed by the kaizen leader. The "before and after" comparison and improvements are presented to the senior management at the end of the event. Team members are formally recognized. Since employees immediately apply their newly learned skills in the improvement project, they retain the skills. Define and distinguish between the steps in this process improvement tool. (Understand) Body of Knowledge V.A.2 2. P lan-D o-Check-Act (PDCA) Cycle PDCA is an improvement cycle methodology that evolved from 1939 to 1994, from Walter A. Shewhart to W. Edwards Deming and improvisation of the model between Ishikawa and the Japanese Quality Circle movement. Figures 16.2–16.5 show variations of the improvement model. The model is a simple circle divided into four quadrants, named "plan," "do," "check," and "act." The improvement team brainstorms the activities that the four quadrants should encompass in the context of the problem at hand and populates the quadrant. Quality gurus like Deming and Ishikawa provided the foundation for this model to build on. H1493 Ramu_p00i-284.indd 160 7/13/16 5:56 PM Chapter 16 A. Improvement Techniques 161 Shewhart straight-line process Step one Step two Step three Specification Production Inspection Shewhart cyclical concept Produc tio n n ctio pe ecification Sp Ins Figure 16.2 Shewhart cycle (1939). Take appropriate action. Check the effects of implementation. Determine goals and targets. Determine methods of reaching goals. Engage in education and training. Implement work. Figure 16.3 Japanese PDCA cycle (1985). 4 1 3 2 1. Design the product (with appropriate tests). 2. Make the product and test in the production line and in the laboratory. 3. Sell the product. 4. Test the product in service and through market research. Find out what users think about it and why nonusers have not bought it. Figure 16.4 Deming wheel (1950). H1493 Ramu_p00i-284.indd 161 7/13/16 5:56 PM 162 Part V Improve and Control Phases Act • What changes are to be made? • Next cycle? • Complete the data analysis. • Compare data with predictions. • Summarize what was learned. Study Plan • Objective. • Questions and predictions. • Plan to carry out the cycle (who, what, where, when). Model for improvement What are we trying to accomplish? How will we know that a change is an improvement? What change can we make that will result in improvement? • Carry out the plan. • Document problems and unexpected observations. • Begin data analysis. Do Act Plan Study Do Figure 16.5 PDSA cycle and model for improvement (1991, 1994). The initial PDCA cycle (Figure 16.2) was created to solve shop floor problems and prevent their recurrence. The seven quality tools were used along with the PDCA model. The model is robust and has many applications, including product design and development, service offering, educational curriculum, and healthcare. Regardless of the application, we can map the activities to PDCA. This forces a disciplined approach to program management and provides team members with the big picture of what needs to be accomplished and where they are in the quadrant. The four quadrants of the improvement PDCA are explained as follows: Plan. Define a problem and hypothesize possible causes and solutions. Do. Implement a solution. Check. Evaluate the results. Act. Return to the Plan step if the results are unsatisfactory or further improvement is required. Standardize the solution if the results are satisfactory. Ishikawa modified the model by incorporating additions to the Plan and Do steps (Figure 16.3): Plan. Determine goals and targets; determine methods of reaching goals Do. Engage in education and training; implement work Check. Check the effects of implementation Act. Take appropriate action At the Plan stage, the process or problem selected for improvement is described. The improvement goals and objectives are defined. H1493 Ramu_p00i-284.indd 162 7/13/16 5:56 PM Chapter 16 A. Improvement Techniques 163 The current process, which is resulting in the problem situation, is described through process mapping. Quality tools are used to analyze the problem and identify the root causes. A cross-functional team is formed to develop a solution and action plan. At the Do stage, the team implements the solution. At the Check stage, the team evaluates the effects of the implementation. At the Act stage, the team takes appropriate actions as to whether to continue the cycle by going back to the Plan stage or to standardize the learning to ensure sustainability of the actions. Deming differentiates his PDSA model (Figure 16.5) from the Japanese PDCA as more of a plan for management. The Study step of the PDSA intends to compare the results with the initial predictions as process learning. The improvement team is encouraged to develop a checklist using the PDCA/PDSA model. Explain the importance of this analysis and how it is used in the improve phase. (Understand) Body of Knowledge V.A.3 3. C ost-Benefit Analysis Once the Analyze phase is completed, the Six Sigma team starts brainstorming to identify improvement actions. Improvement actions can range from rewriting a procedure to redesigning equipment to retrofitting a factory. Every improvement action will cost money to implement. As the saying goes, in order to make money, first you have to spend money. Unless there are significant benefits, improvement actions will not get resourced by management. How do we objectively evaluate the improvement actions? Cost of the improvement actions may involve: Design, development, deployment, sustaining People, equipment, material, environmental controls, software, communication, chart will indicate to the operator that something needs to be adjusted or changed to bring the process back into control. Process behavior charts (statistical process control charts) can be introduced at a high level with the following descriptions: • Typically only six or seven types are used on a regular basis • Create a picture of the process variation while work is being done in real time • Ensure that the process is stable and continuing to operate within the process boundaries established for that process • Provide an early warning to adjust or change the process to bring it back into control • Variable data are continuous (length, mass, time) • Attribute data are discrete (defect, defectives) • Ensure that the measurements from the process are recorded, calculated, and plotted appropriately • Refer to an upper control limit or a lower control limit value from a table • Being in statistical control refers to being between the upper and lower control limits Control charts are used to attain a state of statistical control, monitor a process, and determine process capability. Control charts can monitor process stability and achieve parts per million defect levels. Reduction of variation is achieved through other statistical tools like design of experiments (DOE). A state of statistical control means that only random causes are present in the process (see Chapter 13, "Data Analysis"). It does not mean that products meet specifications. Conversely, a process not in statistical control may still produce H1493 Ramu_p00i-284.indd 173 7/13/16 5:56 PM 174 Part V Improve and Control Phases product conforming to specifications. Basic steps for setting up control charts are as follows: • The recommended number of subgroups is 25 (subgroup size of four or five), sampled at equal intervals from the process during data collection; compute trial control limits. • The data are charted for each subgroup and are reviewed for common and special causes, correcting and removing them... • The mean and standard deviation are estimated based on the sample data. Averages are more sensitive to process changes than individual readings. The control chart is fairly robust for non-normal data. • Control limits based on the statistical variation of the process can be established at ±3 standard deviations from the mean or by using the statistical constants provided in Appendix E. Rational Subgroup A rational subgroup is a sample set that is sufficient to determine common-cause scenarios. Normally, the average of a subgroup is used. In rational subgrouping: • The division of observations into rational subgroups is key • Success of control charting depends on the selection of subgroups (size and frequency of sampling) • Selection should result in groups as homogeneous as possible (no mixing between equipment, manufacturing lines, and tools) Selection of Variables • Key process input variables (KPIVs) may be analyzed to determine their effect on a process • Key process output variables (KPOVs) determine process capability and process monitoring using control charting • DOE and analysis of variance (ANOVA) methods may also identify variables that are significant to process control Variable Selection Variables that are critical to quality should be selected for control chart use. • Importance to customer perception • Objectivity (counted or measured) • Clear indicators to suggest whether quality is being achieved Setting Up Control Charts • Choose the characteristic to be charted based on what is defective and controlled or adjustable (as mentioned earlier). Variable data are preferred to attribute data (i.e., percent defective) and variables data (i.e., numerical measurements) to diagnose causes and determine action. Characteristics of attributes require discrete measurements (i.e., pass/ fail, counts) and will be useful provided that the defective rate is high enough to show on a chart with a reasonable subgroup size. Variables charts require measurements on a continuous scale (i.e., length, mass, and time). • Determine the earliest point in the process where testing can be done to get information on assignable causes. The earlier the cause can be identified, the more likely the consequences can be effectively contained and mitigated. • Choose the type of control chart used: variable or attribute, individual or averages, range or standard deviation. • Decide on the central line and the basis for calculating control limits. • Choose the rational subgroup and the appropriate strategy (subgroup frequency, size, etc.). • Provide the system for collecting data. • Calculate the control limits and provide specific instructions on the interpretation of results and actions to be taken. By identifying and resolving the special causes, the Six Sigma practitioner can facilitate bringing the process into statistical control. At this point, the process results are predictable and the suitability of the process to achieve customer specifications is revealed. From here on, continual improvement can be realized. An example of a variable control chart is presented in Figure 17.4. An example of an attribute control chart is presented in Figure 17.5. Control charts can be used for maintaining statistical control. After the expected process level and dispersion are attained, the expected range of variation will become the standard against which subsequent samples are compared to detect the presence of significant causes of variation. Use of the expected range of variation (sometimes referred to as "natural control limits") as a standard will help detect significant changes in the process. Control charts maintain statistical control and provide traceable evidence through three key actions: • Collection. Run the process and collect the data for plotting on a graph or chart. • Control. Calculate control limits, establish process variability and control limits, and monitor stability • Capability. Establish the ability of the process to meet customer specifications without producing or shipping nonconforming units H1493 Ramu_p00i-284.indd 174 7/13/16 5:56 PM Chapter 17 B. Control Tools and Documentation 175 • Identify the process variables and conditions contributing to product characteristics. • Consider attribute data (i.e., percent defective) and variables data (i.e., numerical measurements) to diagnose causes and determine action. Variables charts require measurements... X and R control chart mp plate w/2B Product/part name and number: Date/operator: 3/17 Time: 7am 1 2 3 4 5 -- Ave, X Range, R: Ave, R: Turner 8 Machine Process 9 10 Gage: 1 Specification limits: 7.125±.010 Subgroup ... Notes: • X 7.134 7.130 7.126 7.122 7.118 R .012 .008 .004 0 – Figure 17.4 X and R control chart example with data plotted. Advantages of Control Charts • Allow operators to collect data at the process • Increase yield by revealing and containing problems at the stage the problem is identified • Provide consistency between operators, shifts, and facilities • Determine whether problems require local or management action Monitoring the Process Monitoring the control chart requires periodic review of variability in the process and review of, or provide solutions to, control limits. H1493 Ramu_p00i-284.indd 176 7/13/16 5:56 PM Chapter 17 Machine/process: p-Chart Product: e Defective = Date: 2015 Operator: Defectives, np # 14 18 13 17 15 15 16 11 14 13 14 17 Sample size: 125 111 133 120 118 137 108 110 124 128 144 138 Fraction, p .11 .16 .10 .13 .11 .15 .10 .11 .10 .12 .14 .10 .020 .016 .012 .080 .040 0 Notes: Figure 17.5 Example of a p-chart. Sustaining the Process Control charts are relatively easy to set up but difficult to sustain. There are many factors that affect continued implementation: • Not making effective use of SPC (data are ceremoniously plotted with no analysis or review to take actions) • Production and productivity seen as more important than time allocation for plotting and monitoring process health • Lack of training of people who plot charts and managers who are required to interpret and take actions Management commitment to resources and to set expectations is key to the success of any quality initiative. H1493 Ramu_p00i-284.indd 177 7/13/16 5:56 PM 178 Part V Improve and Control Phases Documentation Describe the importance of documenting changes to a process and communicating those changes to stakeholders. (Understand) Body of Knowledge V.B.3 3. Document Control Standard Operating Procedures When the process is developed or updated, SOPs should be developed to ensure consistency in the process (whether manufacturing or service). This is one of the methodology under Lean enterprise organization approach to standard work. An SOP is a step-by-step description of how to complete a task. Documented evidence will go a long way in preventing finger-pointing or faultfinding and the operator being blamed for something out of their control. SOPs create consistency and establish the proper methods for completing a process. Standardization is the process of locking in the gains made during the improvement process. Following the SDCA (Standardize-Do-Check-Adjust) process, standardization is done after control plans and process documentation have been updated. Many different terms are used for SOPs, such as "work instructions," "level three ISO 9001 documentation," "operating guides," "job aids," and "standard job practices." SOPs should give the details and address questions such as What is the job? Where does the SOP apply? When does the SOP apply? Who is responsible? Operators are responsible for following the SOPs as written. If at any time the operator deviates from the SOP, the operator needs to document what was done and why. This will be a big help if at a later date a problem arises and an investigation is done. The SOP should be a living document; if something changes in the system, the operator should ensure that the SOP is updated. When something changes in the process and a new desirable level is achieved, the operator should update all documents relating to that process. Changes to documents have to be made in a disciplined manner. Most mature organizations have a process for change management. Changes are reviewed by a designated cross-functional team, approved, and piloted on a small scale through a temporary change notice. Once the results of the pilot are analyzed and the team is convinced of the benefits (no negative impacts elsewhere), the change is formally approved in the system for implementation across the organization or multiple geographical locations. In my experience, organizations and functions that primarily perform research development usually show resistance to documenting changes. There is a misperception that documentation and communication of change is an undervalued administrative work and does not quite fit a creative organization. We as H1493 Ramu_p00i-284.indd 178 7/13/16 5:56 PM Chapter 17 B. Control Tools and Documentation 179 Six Sigma professionals have responsibility to explain the importance of documentation and communication. Documenting changes in a disciplined manner helps the organization trace back and reassess a risk, evaluate customer-reported issues, and so forth. Organizations with ISO 9001 or equivalent management systems implemented have a process to control document changes and communication to stakeholders. It is important to identify the appropriate stakeholders for change review, approval, and communication. Sometimes the stakeholders may be outside the organization, for example, customers, suppliers, and the regulating body. Those with authority to make changes in the organization should also pay attention to retrieve obsolete communications and discard them. It is very easy in an organization to leave old information at various process locations if there is no system for controlled distribution and retrieval. This may cause major confusion and inconsistency in operations where one area is following the old process and another area is using the newly implemented changes. Change management also involves training personnel and mistake proofing the system so that employees do not regress to the old ways. In a typical manufacturing organization, to change a manufacturing document could result in stakeholder communication (Table 17.1). For a service organization, a change in a process document could result in stakeholder communication as shown in Table 17.2. The list of plausible stakeholders can vary case by case. It is recommended that the individual who performs or initiates a change conduct a brainstorming with team members to identify stakeholders affected by the change. Some stakeholders may need to take action based on the change. For example, the change might involve setting up a vendor managed inventory at the organization; the organization's purchasing function should discuss this with the supplier and agree to Table 17.1 Change communication (manufacturing). Function (as an example) Nature of impact Manufacturing Change to related process documentation linked to the affected document Engineering Changes to tools, jigs, fixtures, and gauges; change to equipment maintenance documents Purchasing Changes to purchasing specifications, communication to supplier, assess impact on inventory at supplier location, disposition of affected materials Quality Change to PFMEA, quality control plan, SPC, MSA, control plans Training Change to training documentation IT Changes to application software, testing software Customer support Communication to customer on nature of change and impact (typically informed prior to making change) H1493 Ramu_p00i-284.indd 179 7/13/16 5:56 PM 180 Part V Improve and Control Phases Table 17.2 Change communication (service). Function (as an example) Nature of impact Service delivery Change to related process documentation linked to the affected document Service design Changes to design, service execution Supplier management Changes to purchasing specifications, communication to supplier, assess impact on outsourced service provider Service quality Change to FMEA, service quality plan, SPC, control plan Training Change to training documentation IT Changes to process management software, testing software Customer support Communication to customer on nature of change and impact (typically informed prior to making change) make this a contract condition. Others are communicated as an acknowledgment of the change. Typical change communication documents have check boxes to identify who is impacted by the change and what actions they need to take. Customers often require a written submission of a change proposal for approval before the change is introduced. From the organization's perspective, the change might be small and inconsequential or it could be a change that improves the process. However, the customer might see the change as a risk to product reliability. Functions like environmental health and safety, human resources, and legal may also need to be involved in process changes; for example, a change of chemicals in a cleaning process could violate environmental regulations. If the communication to stakeholders is not well managed, change will not be effectively rolled out. This may result in manufacturing nonconforming products or delivery of services that do not meet customer requirements, product recall, violation notices from regulatory bodies, and unfavorable public relations perceptions. This may also result in a negative impact on the cost of quality metrics, along with a market share that defeats the very purpose of the Six Sigma program. Sustaining process changes are documented ... the proposed changes in the Improve phase are assessed for risk and adequately managed in the Control phase. Questions 1. Develop a control plan for a cake-baking process. Identify whether the requirement is customer-facing or from the process. 2. As a Six Sigma Yellow Belt, you have been asked to identify an appropriate type of control chart for measuring the volume of liquid in a soda can. The manufacturing is a high-volume filling station. You are to select four consecutive soda cans every hour and measure the actual filled volume and record the data. Explain your selection rationale. H1493 Ramu_p00i-284.indd 180 7/13/16 5:56 PM Chapter 17 B. Control Tools and Documentation 181 3. As a Six Sigma Yellow Belt, you have been asked to identify an appropriate type of control chart for a car-painting process. You are to inspect a car every shift and record all the defects found on the painted surface. Explain your selection rationale. (For extra credit, look up in an earlier chapter what type of recording method is ideal for this type of defect capture.) 4. Discuss the key challenges of sustaining process control through control chart usage. 5. Brainstorm additional factors that you know from your experience and share with the class. Recommended solutions. 5. Why is documenting and communicating change important to ensuring the success of Six Sigma projects? H1493 Ramu_p00i-284.indd 181 7/13/16 5:56 PM Part VI Appendices Appendix A ASQ Code of Ethics Appendix B ASQ Certified Six Sigma Yellow Belt (CSSYB) Body of Knowledge (2014) Appendix C ASQ BoK Comparison Appendix D Control Limit Formulas Appendix E Constants for Control Charts Appendix F Areas under Standard Normal Curve Appendix G Binomial Distribution Appendix H Values of the t-Distribution Appendix I Acronym List 183 H1493 Ramu_p00i-284.indd 183 7/13/16 5:56 PM Appendix A ASQ Code of Ethics Fundamental Principles ASQ requires its members and certification holders to conduct themselves ethically by: I. Being honest and impartial in serving the public, their employers, customers, and clients. II. Striving to increase the competence and prestige of the quality profession, and III. Using their knowledge and skill for the enhancement of human welfare. Members and certification holders are required to observe the tenets set forth below: Relations With the Public Article 1—Hold paramount the safety, health, and welfare of the public in the performance of their professional duties. Relations With Employers, Customers, and Clients Article 2—Perform services only in their areas of competence. Article 3—Continue their professional development throughout their careers and provide opportunities for the professional and ethical development of others. Article 4—Act in a professional manner in dealings with ASQ staff and each employer, customer or client. Article 5—Act as faithful agents or trustees and avoid conflict of interest and the appearance of conflicts of interest. 184 H1493 Ramu_p00i-284.indd 184 7/13/16 5:56 PM Appendix A: ASQ Code of Ethics 185 Relations With Peers Article 6—Build their professional reputation on the merit of their services and not compete unfairly with others. Article 7—Assure that credit for the work of others is given to those to whom it is due. Source: H1493 Ramu_p00i-284.indd 185 7/13/16 5:56 PM Appendix B ASQ Certified Six Sigma Yellow Belt (CSSYB) Body of Knowledge (2014) The topics in this Body of Knowledge include additional detail in the form of subtext explanations and the cognitive level at which test questions will be written. This information will provide guidance for the candidate preparing to take the exam. The subtext is not intended to limit the subject matter or be all-inclusive of what might be covered in an exam. It is meant to clarify the type of content to be included in the exam. The descriptor in parentheses at the end of each entry refers to the maximum cognitive level at which the topic will be tested. A complete description of cognitive levels is provided at the end of this document. I. Six Sigma Fundamentals (21 Questions) A. Six Sigma foundations and principles 1. Describe the purpose of six sigma (reducing variation), its methodology (DMAIC) and its evolution from quality. Describe the value of six sigma to the organization as a whole. (Understand) B. Lean foundations and principles. Describe the purpose of lean (waste elimination) and its methodologies (just-in-time, poka-yoke, kanban, value-stream mapping). Describe the value of lean to the organization as a whole. (Understand) C. Six sigma roles and responsibilities. Describe the roles and responsibilities of six sigma team members (i.e., individual team members, yellow belt, green belt, black belt, master black belt, process owner, champion, sponsor). (Understand) D. Team basics 1. Types of teams. Identify the various types of teams that operate within an organization (i.e., continuous improvement, self-managed and cross-functional) and their value. (Understand) 2. Stages of development. Describe the various stages of team evolution: forming, storming, norming, performing, and adjourning. (Understand) 3. Decision-making tools. Define brainstorming, multivoting, and nominal group technique (NGT), and describe how these tools are used by teams. (Understand) H1493 Ramu_p00i-284.indd 186 7/13/16 5:56 PM Part VI: Appendices ASQ Certified Six Sigma Yellow Belt (CSSYB) BoK 187 4. Communication methods. Explain how teams use agendas, meeting minutes, and project status reports, and how they support project success. (Understand) E. Quality tools and six sigma metrics 1. Quality tools. Select and use these tools throughout the DMAIC process: Pareto charts, cause and effect diagrams, flowcharts, run charts, check sheets, scatter diagram, and histograms. (Apply) 2. Six sigma metrics. Select and use these metrics throughout the DMAIC process: defects per unit (DPU), defects per million opportunities (DPMO), rolled throughput yield (RTY), cycle time, and cost of poor quality (COPQ). (Apply) II. Define Phase (12 Questions) A. Project identification 1. Voice of the customer. Define the voice of the customer and describe how customer needs are translated into quantifiable, critical-to-quality (CTQ) characteristics. (Understand) 2. Project selection. Describe how projects are identified and selected as suitable for a six sigma project using the DMAIC methodology. (Understand) 3. Stakeholder analysis. Identify end users, subject matter experts, process owners and other people or factors that will be affected by a project, and describe how each of them can influence the project. (Understand) 4. Process inputs and outputs. Use SIPOC (suppliers, inputs, process, outputs, customers) to identify and define important elements of a process. (Apply) B. Project management (PM) basics 1. Project charter. Describe the purpose of a charter and its components: problem statement, project scope, baseline data, and project goal. (Understand) 2. Communication plan. Explain the purpose and benefits of a communication plan and how it can impact the success of the project. (Understand) 3. Project planning. Define work breakdown structure (WBS) and Gantt charts and describe how they are used to plan and monitor projects. (Understand) H1493 Ramu_p00i-284.indd 187 7/13/16 5:56 PM 188 Part VI: Appendices 4. Project management tools. Identify and use the following PM tools to track projects: basic critical path method, etc. (Apply) 5. Phase reviews. Explain how tollgate or phase reviews are used throughout the DMAIC lifecycle. (Understand) C. Management and planning tools. Define, select, and use 1) affinity diagrams, 2) interrelationship digraphs, 3) tree diagrams, 4) prioritization matrices, 5) matrix diagrams, 6) process decision program charts (PDPC), and 7) activity network diagrams. (Apply) III. Measure Phase (15 Questions) A. Basic statistics. Define, calculate, and interpret measures of central tendency (mean, median, mode) and measures of dispersion (standard deviation, range, variance). (Apply) B. Data collection 1. Data collection plans. Describe the critical elements of a data collection plan, including an operational definition, data sources, the method to be used for gathering data, and how frequently it will be gathered. Describe why data collection plans are important. (Understand) 2. Qualitative and quantitative data. Define and distinguish between these types of data. (Understand) 3. Data collection techniques. Use various data collection techniques, including surveys, interviews, check sheets, and checklists to gather data that contributes to the process being improved. (Apply) C. Measurement system analysis (MSA) 1. MSA terms. Define precision, accuracy, bias, linearity, and stability, and describe how these terms are applied in the measurement phase. (Understand) 2. Gauge repeatability & reproducibility (GR&R). Describe how and why GR&R is used in the measurement phase. (Understand) IV. Analyze Phase (15 Questions) A. Process analysis tools 1. Lean tools. Define how 5S and value analysis can be used to identify and eliminate waste. (Understand) 2. Failure mode and effect analysis (FMEA). Define the elements of severity, opportunity, and detection, how they are used to calculate the risk priority number. Describe how FMEA can be used to identify potential failures in a process. (Understand) B. Root cause analysis. Describe how the 5-whys, process mapping, force-field analysis and matrix charts can be used to identify the root causes of a problem. (Understand) C. Data analysis 1. Basic distribution types. Define and distinguish between normal and binomial distributions and describe how their shapes (skewed and bimodal) can affect data interpretation. (Understand) H1493 Ramu_p00i-284.indd 188 7/13/16 5:56 PM Appendix B: ASQ Certified Six Sigma Yellow Belt (CSSYB) BoK 189 2. Common and special cause variation. Describe and distinguish between these types of variation. (Understand) D. Correlation and regression 1. Correlation. Describe how correlation is used to identify relationships between variables. (Understand) 2. Regression. Describe how regression analysis is used to predict outcomes. (Understand) E. Hypothesis testing. Define and distinguish between hypothesis terms (i.e., null and alternative, type I and type II error, p-value and power). (Understand) V. Improve and Control Phases (12 Questions) A. Improvement techniques 1. Kaizen and kaizen blitz. Define and distinguish between these two methods and describe how they can be used to make improvements to any process in an organization. (Understand) 2. Plan-do-check-act (PDCA) cycle. Define and distinguish between the steps in this process improvement tool. (Understand) 3. Cost-benefit analysis. Explain the importance of this analysis and how it is used in the improve phase. (Understand) B. Control tools and documentation 1. Control plan. Describe the importance of a control plan for maintaining improvements. (Understand) 2. Control charts. Describe how X-R charts are used for monitoring and sustaining improved processes. (Understand) 3. Document control. Describe the importance of documenting changes to a process and communicating those changes to stakeholders. (Understand) Levels of Cognition Based on Bloom's Taxonomy (Revised 2001) In addition to content specifics, the subtext for each topic in this BoK also indicates the intended complexity level of the test questions for that topic. These levels are based on "Levels of Cognition" (from Bloom's Taxonomy—Revised, 2001) and are presented below in rank order, from least complex to most complex. Remember Recall or recognize terms, definitions, facts, ideas, materials, patterns, sequences, methods, principles, etc. H1493 Ramu_p00i-284.indd 189 7/13/16 5:56 PM 190 Part VI: Appendices Understand Read and understand descriptions, communications, reports, tables, diagrams, directions, regulations, etc. Apply Know when and how to use ideas, procedures, methods, formulas, principles, theories, etc. Analyze Break down information into its constituent parts and recognize their relationship to one another and how they are organized; identify sublevel factors or salient data from a complex scenario. Evaluate Make judgments about the value of proposed ideas, solutions, etc., by comparing the proposal to specific criteria or standards. Create Put parts or elements together in such a way as to reveal a pattern or structure not clearly there before; identify which data or information from a complex set is appropriate to examine further or from which supported conclusions can be drawn. H1493 Ramu_p00i-284.indd 190 7/13/16 5:56 PM Appendix C ASQ BoK Comparison CSSYB BoK reference CSSYB BoK reference I. Six Sigma fundamentals (21 questions) A. Six Sigma foundations and principles I.A.1 I.A Describe the purpose of six sigma (reducing variation), its methodology (DMAIC) and its evolution from quality. Describe the value of six sigma to the organization as a whole. (Understand) I.B.1 I.B A. Lean foundations and principles Describe the purpose of lean (waste elimination) and its methodologies (just-in-time, poka-yoke, kanban, value-stream mapping). Describe the value of lean to the organization as a whole. (Understand) I.C.1 I.C Six sigma roles and responsibilities Describe the roles and responsibilities of six sigma team members (i.e., individual team members, yellow belt, green belt, black belt, master black belt, process owner, champion, sponsor). (Understand) II.F.2 D. Team basics I.D.1 I. Types of teams: Identify the various types of teams that operate within an organization (i.e., continuous improvement, self-managed and cross-functional) and their value. (Understand) II.F.2 I.D.2 2. Stages of development: Describe the various stages of team evolution: forming, storming, norming, performing, and adjourning. (Understand) II.F.3 I.D.3 3. Decision-making tools: Define brainstorming, multivoting, and nominal group technique (NGT), and describe how these tools are used by teams. (Understand) II.F.3 I.D.4 4. Communication methods: Explain how teams use agendas, meeting minutes, and project status reports, and how they support project success. (Understand) II.F.4 191 H1493 Ramu_p00i-284.indd 191 7/13/16 5:56 PM 192 Part VI: Appendices CSSYB BoK reference CSSYB BoK reference E. Quality tools and six sigma metrics I.E.1 I.E.1 1. Quality tools: Select and use these tools throughout the DMAIC process: Pareto charts, cause and effect diagrams, flowcharts, run charts, check sheets, scatter diagram, and histograms. (Apply) III.D I.E.2 2. Six sigma metrics: Select and use these metrics throughout the DMAIC process: defects per unit (DPU), defects per million opportunities (DPMO), rolled throughput yield (RTY), cycle time, and cost of poor quality (COPQ). (Apply) II.E II. Define phase (12 questions) A. Project identification II.A.1 1. Voice of the customer: Define the voice of the customer and describe how customer needs are translated into quantifiable, critical-to-quality (CTQ) characteristics. (Understand) I.A.2, II.A.1 II.A.2 2. Project selection: Describe how projects are identified and selected as suitable for a six sigma project using the DMAIC methodology. (Understand) I.A.2, II.A.3 3. Stakeholder analysis: Identify end users, subject matter experts, process owners and other people or factors that will be affected by a project, and describe how each of them can influence the project. (Understand) I.A.2, II.A.4 4. Process inputs and outputs: Use SIPOC (suppliers, inputs, process, outputs, customers) to identify and define important elements of a process. (Apply) I.A.2 B. Project management (PM) basics II.B.1 1. Project charter: Describe the purpose of a charter and its components: problem statement, project scope, baseline data, and project goal. (Understand) II.C.1, II.C.2 II.B.2 2. Communication plan: Explain the purpose and benefits of a communication plan and how it can impact the success of the project. (Understand) I.E.2 II.B.3 3. Project planning: Define work breakdown structure (WBS) and Gantt charts and describe how they are used to plan and monitor projects. (Understand) II.B.4 4. Project management tools: Identify and use the following PM tools to track projects: basic critical path method. (Apply) II.D.1 II.B.5 5. Phase reviews: Explain how tollgate or phase reviews are used throughout the DMAIC lifecycle. (Understand) II.C.4 H1493 Ramu_p00i-284.indd 192 7/13/16 5:56 PM Appendix C: ASQ BoK Comparison 193 CSSYB BoK reference CSSYB BoK reference III. Measure phase (15 questions) A. Basic statistics III.A Define, calculate, and interpret measures of central tendency (mean, median, mode) and measures of dispersion (standard deviation, range, variance). (Apply) III.B.2, III.D.3 B. Data collection III.B.1 1. Data collection plans: Describe the critical elements of a data collection plan, including an operational definition, data sources, the method to be used for gathering data, and how frequently it will be gathered. Describe why data collection plans are important. (Understand) III.A.1 III.B.2 2. Qualitative and quantitative data: Define and distinguish between these types of data. (Understand) III.A.1 III.B.3 3. Data collection techniques: Use various data collection techniques, including surveys, interviews, check sheets, and checklists to gather data that contributes to the process being improved. (Apply) III.A.3 C. Measurement system analysis (MSA) III.C.1 1. MSA terms: Define precision, accuracy, bias, linearity, and stability, and describe how these terms are applied in the measurement phase. (Understand) III.C.2 2. Gauge repeatability & reproducibility (GR&R): Describe how and why GR&R is used in the measurement phase. (Understand) IV. Analyze phase (15 questions) A. Process analysis tools IV.A.1 1. Lean tools: Define how 5S and value analysis can be used to identify and eliminate waste. (Understand) IV.A.2 2. Failure mode and effect analysis (FMEA): Define the elements of severity, opportunity, and detection, how they are used to calculate the risk priority number. Describe how FMEA can be used to identify potential failures in a process. (Understand) I.C.2, I.C.3 B. Root cause analysis IV.B H1493 Ramu_p00i-284.indd 193 7/13/16 5:56 PM 194 Part VI: Appendices CSSYB BoK reference CSSYB BoK reference Describe how the 5-whys, process mapping, force-field analysis and matrix charts can be used to identify the root causes of a problem. (Understand) IV.A.3 C. Data analysis IV.C.1 1. Basic distribution types: Define and distinguish between normal and binomial distributions and describe how their shapes (skewed and bimodal) can affect data interpretation. (Understand) IV.C.2 2. Common and special cause variation: Describe and distinguish between these types of variation. (Understand) IV.D.1 D. Correlation and regression 1. Correlation: Describe how correlation is used to identify relationships between variables. (Understand) IV.A.2 IV.D.2 2. Regression: Describe how regression analysis is used to predict outcomes. (Understand) IV.A.2 E. Hypothesis testing Define and distinguish between hypothesis terms (i.e., null and alternative, type I and type II error, p-value and power). (Understand) V. Improve and control phases (12 questions) A. Improvement techniques V.A.1 1. Kaizen and kaizen blitz: Define and distinguish between these two methods and describe how they can be used to make improvements to any process in an organization. (Understand) V.A.2 2. Plan-do-check-act (PDCA) cycle: Define and distinguish between the steps in this process improvement tool. (Understand) V.A.3 3. Cost-benefit analysis: Explain the importance of this analysis and how it is used in the improve phase. (Understand) B. Control tools and documentation V.B.1 1. Control plan: Describe the importance of a control plan for maintaining improvements. (Understand) V.B.2 2. Control charts: Describe how X-R charts are used for monitoring and sustaining improved processes. (Understand) V.B.3 3. Document control: Describe the importance of documenting changes to a process and communicating those changes to stakeholders. (Understand) H1493 Ramu_p00i-284.indd 194 7/13/16 5:56 PM Appendix D Control Limit Formulas Variables Charts $\bar{x}$ and R chart: Averages chart : $\bar{x} \pm A_2 \bar{R}$ Range chart : LCL = $D_3 \bar{R}$ UCL = $D_4 \bar{R}$ $\bar{x}$ and s chart: Averages chart : $\bar{x} \pm A_3 \bar{s}$ Standard deviation chart : LCL = $B_3 \bar{s}$ UCL = $B_4 \bar{s}$ Individuals and moving range chart (two-value moving window): Individuals chart : $\bar{x} \pm 2.66\bar{R}$ Moving range : UCL = $3.267 \bar{R}$ Moving average and moving range (two-value moving window): Moving average : $\bar{x} \pm 1.88\bar{R}$ Moving range : UCL = $3.267 \bar{R}$ Median chart: Median chart : $\bar{x}' \pm A_2' \bar{R}$ Range chart : LCL = $D_3 \bar{R}$ UCL = $D_4 \bar{R}$ Attributes Charts Variable sample size: Constant sample size: p chart: $\bar{p} \pm 3 \sqrt{\bar{p}(1-\bar{p})/n}$ u chart: $\bar{u} \pm 3\sqrt{\bar{u}/n}$ D chart: $\bar{D} \pm 3\sigma D$ n u n np chart: $n\bar{p} \pm 3\sqrt{n\bar{p}(1-\bar{p})}$ c chart: $\bar{c} \pm 3\sqrt{\bar{c}}$ U chart: $\bar{U} \pm 3\sigma U$ 195 H1493 Ramu_p00i-284.indd 195 7/13/16 5:56 PM Appendix E Constants for Control Charts S u b g ro u p size N A2 d2 D3 D4 A3 c4 B3 B4 E2 A2 for median charts 2 1.880 1.128 – 3.267 2.659 0.798 – 3.267 2.660 1.880 2.224 3 1.023 1.693 – 2.574 1.954 0.886 – 2.568 1.772 1.187 1.091 4 0.729 2.059 – 2.282 1.628 0.921 – 2.266 1.457 0.796 0.758 5 0.577 2.326 – 2.114 1.427 0.940 – 2.089 1.290 0.691 0.594 6 0.483 2.534 – 2.004 1.287 0.952 0.030 1.970 1.184 0.548 0.495 7 0.419 2.704 0.076 1.924 1.182 0.959 0.118 1.882 1.109 0.508 0.429 8 0.373 2.847 0.136 1.864 1.099 0.965 0.185 1.815 1.054 0.433 0.380 9 0.337 2.970 0.184 1.816 1.032 0.969 0.239 1.761 1.010 0.412 0.343 10 0.308 3.078 0.223 1.777 0.975 0.973 0.284 1.716 0.975 0.362 0.314 A4 196 H1493 Ramu_p00i-284.indd 196 7/13/16 5:56 PM Appendix F Areas under Standard Normal Curve z 0.00 0.01 0.02 0.03 0.04 0.0 0.50000000000 0.49601064369 0.49202168628 0.48803352659 0.48404656315 0.1 0.46017216272 0.45620468746 0.45224157398 0.44828321335 0.44432995519 0.2 0.42074029056 0.41683383652 0.41293557735 0.40904588486 0.40516512830 0.3 0.38208857781 0.37828047818 0.37448416528 0.37069998106 0.36692826396 0.4 0.34457825839 0.34090297377 0.33724272685 0.33359782060 0.32996855366 0.5 0.30853753873 0.30502573090 0.30153178755 0.29805596539 0.29459851622 0.6 0.27425311775 0.27093090378 0.26762889347 0.26434729212 0.26108629969 0.7 0.24196365222 0.23885206809 0.23576249778 0.23269509230 0.22964999716 0.8 0.21185539858 0.20897008787 0.20610805359 0.20326939183 0.20045419326 0.9 0.18406012535 0.18141125489 0.17878637961 0.17618554225 0.17360878034 1.0 0.15865525393 0.15624764502 0.15386423037 0.15150500279 0.14916995033 1.1 0.13566606095 0.13349951324 0.13135688104 0.12923811224 0.12714315056 1.2 0.11506967022 0.11313944644 0.11123243745 0.10934855243 0.10748769707 1.3 0.09680048459 0.09509791780 0.09341750899 0.09175913565 0.09012267246 1.4 0.08075665923 0.07926984145 0.07780384053 0.07635850954 0.07493369953 1.5 0.06680720127 0.06552171209 0.06425548782 0.06300836446 0.06178017671 1.6 0.05479929170 0.05369892815 0.05261613845 0.05155074849 0.05050258347 1.7 0.04456546276 0.04363293652 0.04271622079 0.04181513761 0.04092950898 1.8 0.03593031911 0.03514789358 0.03437950245 0.03362496942 0.03288411866 1.9 0.02871655982 0.02806660666 0.02742894970 0.02680341888 0.02618984494 2.0 0.02275013195 0.02221559443 0.02169169377 0.02117826964 0.02067516287 2.1 0.01786442056 0.01742917794 0.01700302265 0.01658580668 0.01617738337 2.2 0.01390344751 0.01355258115 0.01320938381 0.01287372144 0.01254546144 2.3 0.01072411002 0.01044407706 0.01017043867 0.00990307556 0.00964186995 2.4 0.00819753592 0.00797626026 0.00776025355 0.00754941142 0.00734363096 2.5 0.00620966533 0.00603655808 0.00586774172 0.00570312633 0.00554262344 2.6 0.00466118802 0.00452711113 0.00439648835 0.00426924341 0.00414530136 2.7 0.00346697380 0.00336416041 0.00326409582 0.00316671628 0.00307195922 2.8 0.00255513033 0.00247707500 0.00240118247 0.00232740021 0.00225567669 2.9 0.00186581330 0.00180714378 0.00175015693 0.00169481002 0.00164106123 (continued) Continued 197 H1493 Ramu_p00i-284.indd 197 7/13/16 5:56 PM 198 Part VI: Appendices Continued z 0.00 0.01 0.02 0.03 0.04 3.0 0.00134989803 0.00130623845 0.00126387343 0.00122276869 0.00118289074 3.1 0.00096760321 0.00093543672 0.00090425520 0.00087403152 0.00084473917 3.2 0.00068713794 0.00066367486 0.00064095298 0.00061895109 0.00059764850 3.3 0.00048342414 0.00046647986 0.00045008724 0.00043422992 0.00041889195 3.4 0.00033692927 0.00032481440 0.00031310568 0.00030179062 0.00029085709 3.5 0.00023262908 0.00022405335 0.00021577340 0.00020777983 0.00020006352 3.6 0.00015910859 0.00015309850 0.00014730151 0.00014171061 0.00013631902 3.7 0.00010779973 0.00010362962 0.00009961139 0.00009573989 0.00009201013 3.8 0.00007234804 0.00006948340 0.00006672584 0.00006407163 0.00006151716 3.9 0.00004809634 0.00004614806 0.00004427448 0.00004247293 0.00004074080 4.0 0.00003167124 0.00003035937 0.00002909907 0.00002788843 0.00002672560 4.1 0.00002065751 0.00001978296 0.00001894362 0.00001813816 0.00001736529 4.2 0.00001334575 0.00001276853 0.00001221512 0.00001168457 0.00001117599 4.3 0.00000853991 0.00000816273 0.00000780146 0.00000745547 0.00000712414 4.4 0.00000541254 0.00000516853 0.00000493505 0.00000471165 0.00000449794 4.5 0.00000339767 0.00000324138 0.00000309198 0.00000294918 0.00000281271 4.6 0.00000211245 0.00000201334 0.00000191870 0.00000182833 0.00000174205 4.7 0.00000130081 0.00000123858 0.00000117922 0.00000112260 0.00000106859 4.8 0.00000079333 0.00000075465 0.00000071779 0.00000068267 0.00000064920 4.9 0.00000047918 0.00000045538 0.00000043272 0.00000041115 0.00000039061 5.0 0.00000028665 0.00000027215 0.00000025836 0.00000024524 0.00000023277 5.1 0.00000016983 0.00000016108 0.00000015277 0.00000014487 0.00000013737 5.2 0.00000009964 0.00000009442 0.00000008946 0.00000008476 0.00000008029 5.3 0.00000005790 0.00000005481 0.00000005188 0.00000004911 0.00000004647 5.4 0.00000003332 0.00000003151 0.00000002980 0.00000002818 0.00000002664 5.5 0.00000001899 0.00000001794 0.00000001695 0.00000001601 0.00000001512 5.6 0.00000001072 0.00000001012 0.00000000955 0.00000000901 0.00000000850 5.7 0.00000000599 0.00000000565 0.00000000533 0.00000000502 0.00000000473 5.8 0.00000000332 0.00000000312 0.00000000294 0.00000000277 0.00000000261 5.9 0.00000000182 0.00000000171 0.00000000161 0.00000000151 0.00000000143 6.0 0.00000000099 0.00000000093 0.00000000087 0.00000000082 0.00000000077 Continued (continued) H1493 Ramu_p00i-284.indd 198 7/13/16 5:56 PM Appendix F: Areas under Standard Normal Curve 199 Continued z 0.05 0.06 0.07 0.08 0.09 0.0 0.48006119416 0.47607781735 0.47209682982 0.46811862799 0.46414360741 0.1 0.44038230763 0.43644053711 0.43250506832 0.42857628410 0.42465456527 0.2 0.40129367432 0.39743188680 0.39358012680 0.38973875244 0.38590811880 0.3 0.36316934882 0.35942356678 0.35569124520 0.35197270758 0.34826827346 0.4 0.32635522029 0.32275811025 0.31917750878 0.31561369652 0.31206694942 0.5 0.29115968679 0.28773971885 0.28433884905 0.28095730890 0.27759532475 0.6 0.25784611081 0.25462691467 0.25142889510 0.24825223045 0.24509709367 0.7 0.22662735238 0.22362729244 0.22064994634 0.21769543759 0.21476388416 0.8 0.19766254312 0.19489452125 0.19215020210 0.18942965478 0.18673294304 0.9 0.17105612631 0.16852760747 0.16602324606 0.16354305933 0.16108705951 1.0 0.14685905638 0.14457229966 0.14230965436 0.14007109009 0.13785657203 1.1 0.12507193564 0.12302440305 0.12100048442 0.11900010746 0.11702319602 1.2 0.10564977367 0.10383468112 0.10204231507 0.10027256795 0.09852532905 1.3 0.08850799144 0.08691496195 0.08534345082 0.08379332242 0.08226443868 1.4 0.07352925961 0.07214503697 0.07078087699 0.06943662333 0.06811211797 1.5 0.06057075800 0.05937994059 0.05820755564 0.05705343324 0.05591740252 1.6 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0.00001662376 0.00001591238 0.00001522998 0.00001457545 0.00001394772 4.2 0.00001068853 0.00001022135 0.00000977365 0.00000934467 0.00000893366 4.3 0.00000680688 0.00000650312 0.00000621233 0.00000593397 0.00000566753 4.4 0.00000429351 0.00000409798 0.00000391098 0.00000373215 0.00000356116 4.5 0.00000268230 0.00000255768 0.00000243862 0.00000232488 0.00000221623 4.6 0.00000165968 0.00000158105 0.00000150600 0.00000143437 0.00000136603 4.7 0.00000101708 0.00000096796 0.00000092113 0.00000087648 0.00000083391 4.8 0.00000061731 0.00000058693 0.00000055799 0.00000053043 0.00000050418 4.9 0.00000037107 0.00000035247 0.00000033476 0.00000031792 0.00000030190 5.0 0.00000022091 0.00000020963 0.00000019891 0.00000018872 0.00000017903 5.1 0.00000013024 0.00000012347 0.00000011705 0.00000011094 0.00000010515 5.2 0.00000007605 0.00000007203 0.00000006821 0.00000006459 0.00000006116 5.3 0.00000004398 0.00000004161 0.00000003937 0.00000003724 0.00000003523 5.4 0.00000002518 0.00000002381 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0.999 0.997 0.995 0.993 0.990 0.986 0.982 0.977 0.972 0.939 0.896 0.844 0.784 0.718 0.648 0.575 0.500 3 2 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.999 0.999 0.997 0.992 0.984 0.973 0.957 0.936 0.909 0.875 4 0 0.961 0.922 0.885 0.849 0.815 0.781 0.748 0.716 0.686 0.656 0.522 0.410 0.316 0.240 0.179 0.130 0.092 0.063 4 1 0.999 0.998 0.995 0.991 0.986 0.980 0.973 0.966 0.957 0.948 0.890 0.819 0.738 0.652 0.563 0.475 0.391 0.313 4 2 1.000 1.000 1.000 1.000 1.000 0.999 0.999 0.998 0.997 0.996 0.988 0.973 0.949 0.916 0.874 0.821 0.759 0.688 4 3 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.998 0.996 0.992 0.985 0.974 0.959 0.938 5 0 0.951 0.904 0.859 0.815 0.774 0.734 0.696 0.659 0.624 0.590 0.444 0.328 0.237 0.168 0.116 0.078 0.050 0.031 5 1 0.999 0.996 0.992 0.985 0.977 0.968 0.958 0.946 0.933 0.919 0.835 0.737 0.633 0.528 0.428 0.337 0.256 0.188 5 2 1.000 1.000 1.000 0.999 0.999 0.998 0.997 0.995 0.994 0.991 0.973 0.942 0.896 0.837 0.765 0.683 0.593 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0.028 0.015 0.008 7 1 0.998 0.992 0.983 0.971 0.956 0.938 0.919 0.897 0.875 0.850 0.717 0.577 0.445 0.329 0.234 0.159 0.102 0.063 7 2 1.000 1.000 0.999 0.998 0.996 0.994 0.990 0.986 0.981 0.974 0.926 0.852 0.756 0.647 0.532 0.420 0.316 0.227 7 3 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.999 0.998 0.997 0.988 0.967 0.929 0.874 0.800 0.710 0.608 0.500 7 4 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.995 0.987 0.971 0.944 0.904 0.847 0.773 7 5 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.996 0.991 0.981 0.964 0.938 7 6 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.998 0.996 0.992 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 Continued (continued) 201 H1493 Ramu_p00i-284.indd 201 7/13/16 5:56 PM 202 Part VI: Appendices (Continued) Binomial distribution (continued) p n x 8 0 0.923 0.851 0.784 0.721 0.663 0.610 0.560 0.513 0.470 0.430 0.272 0.168 0.100 0.058 0.032 0.017 0.008 0.004 8 1 0.997 0.990 0.978 0.962 0.943 0.921 0.897 0.870 0.842 0.813 0.657 0.503 0.367 0.255 0.169 0.106 0.063 0.035 8 2 1.000 1.000 0.999 0.997 0.994 0.990 0.985 0.979 0.971 0.962 0.895 0.797 0.679 0.552 0.428 0.315 0.220 0.145 8 3 1.000 1.000 1.000 1.000 1.000 0.999 0.999 0.998 0.997 0.995 0.979 0.944 0.886 0.806 0.706 0.594 0.477 0.363 8 4 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.997 0.990 0.973 0.942 0.894 0.826 0.740 0.637 8 5 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.996 0.989 0.975 0.950 0.912 0.855 8 6 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.996 0.991 0.982 0.965 8 7 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.998 0.996 9 0 0.914 0.834 0.760 0.693 0.630 0.573 0.520 0.472 0.428 0.387 0.232 0.134 0.075 0.040 0.021 0.010 0.005 0.002 9 1 0.997 0.987 0.972 0.952 0.929 0.902 0.873 0.842 0.809 0.775 0.599 0.436 0.300 0.196 0.121 0.071 0.039 0.020 9 2 1.000 0.999 0.998 0.996 0.992 0.986 0.979 0.970 0.960 0.947 0.859 0.738 0.601 0.463 0.337 0.232 0.150 0.090 9 3 1.000 1.000 1.000 1.000 0.999 0.999 0.998 0.996 0.994 0.992 0.966 0.914 0.834 0.730 0.609 0.483 0.361 0.254 9 4 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.999 0.994 0.980 0.951 0.901 0.828 0.733 0.621 0.500 9 5 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.997 0.990 0.975 0.946 0.901 0.834 0.746 9 6 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.996 0.989 0.975 0.950 0.910 9 7 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.998 0.996 0.991 0.980 9 8 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.998 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 10 0 0.904 0.817 0.737 0.665 0.599 0.539 0.484 0.434 0.389 0.349 0.197 0.107 0.056 0.028 0.013 0.006 0.003 0.001 10 1 0.996 0.984 0.965 0.942 0.914 0.882 0.848 0.812 0.775 0.736 0.544 0.376 0.244 0.149 0.086 0.046 0.023 0.011 10 2 1.000 0.999 0.997 0.994 0.988 0.981 0.972 0.960 0.946 0.930 0.820 0.678 0.526 0.383 0.262 0.167 0.100 0.055 10 3 1.000 1.000 1.000 1.000 0.999 0.999 0.998 0.996 0.994 0.991 0.987 0.950 0.879 0.776 0.650 0.514 0.382 0.266 0.172 10 4 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.999 0.998 0.990 0.967 0.922 0.850 0.751 0.633 0.504 0.377 10 5 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 0.999 0.994 0.980 0.953 0.905 0.834 0.738 0.623 H1493 Ramu_p00i-284.indd 202 7/13/16 5:56 PM Appendix H Values of the t-Distribution Values of t distribution m m t 0.100 t 0.050 t 0.025 t 0.010 t 0.005 1 3.078 6.314 12.706 31.821 63.656 1 2 1.886 2.920 4.303 6.965 9.925 2 3 1.638 2.353 3.182 4.541 5.841 3 4 1.533 2.132 2.776 3.747 4.604 4 5 1.476 2.015 2.571 3.365 4.032 5 6 1.440 1.943 2.447 3.143 3.707 6 7 1.415 1.895 2.365 2.998 3.499 7 8 1.397 1.860 2.306 2.896 3.355 8 9 1.383 1.833 2.262 2.821 3.250 9 10 1.372 1.812 2.228 2.764 3.169 10 11 1.363 1.796 2.201 2.718 3.106 11 12 1.356 1.782 2.179 2.681 3.055 12 13 1.350 1.771 2.160 2.650 3.012 13 14 1.345 1.761 2.145 2.624 2.977 14 15 1.341 1.753 2.131 2.602 2.947 15 16 1.337 1.746 2.120 2.583 2.921 16 17 1.333 1.740 2.110 2.567 2.898 17 18 1.330 1.734 2.101 2.552 2.878 18 19 1.328 1.729 2.093 2.539 2.861 19 20 1.325 1.725 2.086 2.528 2.845 20 21 1.323 1.721 2.080 2.518 2.831 21 22 1.321 1.717 2.074 2.508 2.819 22 23 1.319 1.714 2.069 2.500 2.807 23 24 1.318 1.711 2.064 2.492 2.797 24 25 1.316 1.708 2.060 2.485 2.787 25 26 1.315 1.706 2.056 2.479 2.779 26 27 1.314 1.703 2.052 2.473 2.771 27 28 1.313 1.701 2.048 2.467 2.763 28 Continued (continued) 203 H1493 Ramu_p00i-284.indd 203 7/13/16 5:56 PM 204 Part VI: Appendices (Continued) Values of t distribution (continued) m m t 0.10 t 0.05 t 0.025 t 0.01 t 0.005 29 1.311 1.699 2.045 2.462 2.756 29 30 1.310 1.697 2.042 2.457 2.750 30 31 1.309 1.696 2.040 2.453 2.744 31 32 1.309 1.694 2.037 2.449 2.738 32 33 1.308 1.692 2.035 2.445 2.733 33 34 1.307 1.691 2.032 2.441 2.728 34 35 1.306 1.690 2.030 2.438 2.724 35 40 1.303 1.684 2.021 2.423 2.704 40 45 1.301 1.679 2.014 2.412 2.690 45 50 1.299 1.676 2.009 2.403 2.678 50 55 1.297 1.673 2.004 2.396 2.668 55 60 1.296 1.671 2.000 2.390 2.660 60 70 1.294 1.667 1.994 2.381 2.648 70 80 1.292 1.664 1.990 2.374 2.639 80 90 1.291 1.662 1.987 2.368 2.632 90 100 1.290 1.660 1.984 2.364 2.626 100 200 1.286 1.653 1.972 2.345 2.601 200 400 1.284 1.649 1.966 2.336 2.588 400 600 1.283 1.647 1.964 2.333 2.584 600 800 1.283 1.647 1.963 2.331 2.582 800 999 1.282 1.646 1.962 2.330 2.581 999 H1493 Ramu_p00i-284.indd 204 7/13/16 5:56 PM Appendix I Acronym List 14 Points—Doctor Deming's 14 management practices 3C—cognition, conscience, commitment 3D—dirty, dangerous, difficult 3P—people, planet, profit 3P—people, product, process 3P—production preparation process 5M&P—materials, methods, machines, measurement, Mother Nature, and people 5P—Honda problem solving approach 5S—sort (seiri), straighten (seiton), shine (seiso), standardize (seiketsu), sustain (shitsuke) 5W1H—what, where, when, why, who, and how 6S—5S with safety added 7P—proper prior planning prevents piss poor performance 7S—6S with oversight added 8D—eight disciplines of problem solving 8M—man (people), machine (equipment), methods (operating procedures), materials, measurement, Mother Nature (environment), management, and money A2LA—American Association for Laboratory Accreditation A3—executive report on one page ABET—ABET, Inc. (formerly the Accreditation Board of Education and Training) AD—Anderson-Darling test AHP—analytic hierarchy process AHT—average handling time AIAG—Automotive Industry Action Group AMA—American Management Association 205 H1493 Ramu_p00i-284.indd 205 7/13/16 5:56 PM 206 Part VI: Appendices ANAB—American National Accreditation Board AND—activity network diagram ANOM—analysis of means ANOVA—analysis of variance ANSI—American National Standards Institute AOQ—average outgoing quality AOQL—average outgoing quality limit APQP—advanced product quality planning AQL—acceptable quality level AQP—advanced quality planning AQP—Association for Quality and Participation AQS—advanced quality system AQT—acceptable quality test ARL—average run length AS—aerospace standards ASA—American Statistical Association ASCII—American standard code for information interchange ASEE—American Society for Engineering Education ASI—American Supplier Institute ASME—American Society of Mechanical Engineers ASN—average sample number ASNT—American Society for Nondestructive Testing ASQ—American Society for Quality ASQC—American Society for Quality Control (ASQ name before 1997) ASSE—American Society for Safety Engineers ASTD—American Society for Training and Development ASTM—ASTM International—formerly American Society for Testing and Materials AV—appraiser variation B2C—business to customer BB—Black Belt BBS—behavior based safety H1493 Ramu_p00i-284.indd 206 7/13/16 5:56 PM Appendix I: Acronym List 207 BIA—business impact analysis BIB—balanced incomplete block design BIC—best in class BIC—business improvement coach BIT—built-in test BITE—built-in test equipment BOB—best of the best BoK—body of knowledge BOM—bill of materials BOS—business operating system BPR—business process reengineering BSI—British Standards Institute BTW—by the way C&E—cause and effect C/N—change notice C/O—changeover time C/T—cycle time CAD—computer-aided design CADQAD—computer-aided development of quality assurance data CAE—computer-aided engineering CAFÉ—corporate average fuel economy CAM—computer-aided manufacturing CANDO—clean up, arranging, neatness, discipline, ongoing improvement CAP—change acceleration process CAP—corrective action plan CAPA—corrective and preventive action CAQ—computer-aided quality assurance CAR—corrective action recommendation CAR—corrective action report CASE—computer-aided software engineering CASE—coordinated aerospace supplier evaluation CBA—ASQ Certified Biomedical Auditor H1493 Ramu_p00i-284.indd 207 7/13/16 5:56 PM 208 Part VI: Appendices CBP—customer benefits package CBT—computer-based training CC—critical characteristic CCR—capacity constraint resource CCR—critical customer requirement CCT—ASQ Certified Calibration Technician CE—cause and effect (for example, CE matrix) CE—concurrent engineering CEDAC—cause-and-effect diagram with additional cards CEO—chief executive officer CEPT—Centre (for) Environmental Planning (and) Technology [India] CFO—chief financial officer CFR—USA Code of Federal Regulations CGMP—current good manufacturing practice CHA—ASQ Certified HACCP Auditor CI—continual improvement CIM—change-in-mean-effect CIO—chief information officer CIT—critical items list CLCA—closed-loop corrective action Cm—capability machine CM—condition monitoring CMI—ASQ Certified Mechanical Inspector Cmk—machine capability index CMM—capability maturity model for software (also known as SW-CMM) CMM—coordinate measuring machine CMQ/OE—ASQ Certified Manager of Quality and Operational Excellence CMQOE—ASQ Certified Manager of Quality Organizational Excellence CNC—computer numerical control COA—certificate of analysis COB—chairman of board COB—close of business H1493 Ramu_p00i-284.indd 208 7/13/16 5:56 PM Appendix I: Acronym List 209 COC—certificate of conformance COC—cost of conformance COCQ—cost of current quality CONC—cost of nonconformance COO—chief operating officer COP—code of practice COP—customer oriented process COPIS—customer, output, process, input, supplier COPQ—cost of poor quality—measure of waste in operation COQ—cost of quality (see COPQ) COQC—certificate of quality compliance CP—control plan CPR—corrective preventive report Cp—Process capability measurement—compares engineering specification divided by process six standard deviations Cpk—Process capability measurement—compares engineering specification to process mean divided by three standard deviations CPM—critical path method CPN—critical path network CPU—cost per unit CQA—ASQ Certified Quality Auditor CQA—contract quality assurance CQE—ASQ Certified Quality Engineer CQIA—ASQ Certified Quality Improvement Associate CQM—Center for Quality of Management CQMP—clinical quality management program CQP—corporate quality policies CQPA—ASQ Certified Quality Process Analyst CQR—contract quality requirement CQT—ASQ Certified Quality Technician CR—conditionally required Cr—ratio of process variation CR/CR—concern report/change request H1493 Ramu_p00i-284.indd 209 7/13/16 5:56 PM 210 Part VI: Appendices CRE—ASQ Certified Reliability Engineer CRM—certified reference material CRM—corporate records management CRM—customer relationship management CS—customer satisfaction CSA—compliance safety accountability CSF—critical success factors CSM—customer–supplier model CSP—continuous sampling plan CSQE—ASQ Certified Software Quality Engineer CSSBB—ASQ Certified Six Sigma Black Belt CSSGB—ASQ Certified Six Sigma Green Belt CSSMBB—ASQ Certified Six Sigma Master Black Belt CSSYB—ASQ Certified Six Sigma Yellow Belt CTC—critical to customer CTQ—critical to quality CTS—critical to satisfaction CUSUM—cumulative sum control chart CVEP—continuous value enhancement process CWAP—Clean Water Action Plan CWQC—company-wide quality control D—detection DAX—desire, attitude, execution DBR—discounted cash flow DCCDI—define–customer–concept–design–implement DCF—discounted cash flow DCOV—define–characterize–optimize–verify DCP—dynamic control plan DDW—drill deep and wide DE—directed evolution DER—designated engineering representative df—degrees of freedom H1493 Ramu_p00i-284.indd 210 7/13/16 5:56 PM Appendix I: Acronym List 211 DFA—design for assembly DFD—design for disassembly DFE—design for ergonomics DFM—design for manufacturing DFMA—design for manufacturing and assembly DFMEA—design failure mode and effects analysis DFSS—design for Six Sigma DFX—design for X DMADOV—define–measure–analyze–design–optimize–verify DMADV—define–measure–analyze–design–verify DMAIC—define, measure, analyze, improve, and control DMEDI—define–measure–explore–develop–implement DOE—design of experiment(s) DOT—United States Department of Transportation DPM—deficiencies (defects) per million units DPMO—deficiencies (defects) per million opportunities DPO—deficiencies (defects) per opportunity DPPM—defective parts per million DPU—deficien DPU—deficiencies (defects) per unit DQC—data quality control DRBFM—design review based on failure mode (Toyota version of FMEA) DSL—digital subscriber line DSU—digital service unit DTD—dock to delivery DV&PR—design verification and product reliability DVP—design verification plan DVP&PV—design verification, production and process validation DVR—design verification report DVT—design verification test EARA—Environmental Auditors Registration Association EC—European Community H1493 Ramu_p00i-284.indd 211 7/13/16 5:56 PM 212 Part VI: Appendices ECC—estimated cost to complete ECDF—empirical cumulative distribution function ECN—engineering change notice ECO—engineer change order ECR—engineering change request EDA—exploratory data analysis EDI—electronic data interchange EI—employee involvement EIO—engineering or installation caused outage ELT—extract load transfer EMI—electromagnetic interference EMS—environmental management system EOQ—economic order quantity EPSS—electronic performance support system ER—engineering requirements ERI—early return indicator ERP—enterprise resource planning ES—engineering specification ESC—extreme service conditions ESER—engineering sample evaluation report ET—educational technology ETA—event tree analysis EU—European Union EV—equipment variation EVOP—evolutionary operation EWMA—exponentially weighted moving average FAHQMT—fully automatic high-quality machine translation FAI—first article inspection FAIR—first article inspection report FAR—Federal Acquisition Regulation FAST—function analysis system technique FCE—frequently committed errors H1493 Ramu_p00i-284.indd 212 7/13/16 5:56 PM Appendix I: Acronym List 213 FEA—finite element analysis FEA—front-end analysis FIFO—first in, first out FISH—first in still here FMA—failure mode analysis FMEA—failure mode and effects analysis FMECA—failure mode effects and criticality analysis FMEDA—failure modes, effects, and diagnostic analysis FMEM—failure mode effects management FPA—first party audit FPS—Ford Production System FQ&P—flight, quality, and performance FQI—Federal Quality Institute (see OPM) FR—field replaceable unit returns FRT—fix response time FSL—flow synchronization leveling FSS—full service supplier FTA—fault tree analysis FTPM—Ford Total Productive Maintenance FTQ—first time quality FTT—first time through G8D—global eight disciplines GB—Green Belt GD&T—geometric dimensioning and tolerancing GE—General Electric Corporation GLM—general linear model GLP—good laboratory practice GM—General Motors Corporation GMP—good manufacturing practice GPC—gage performance curve GR&R—gage repeatability and reproducibility GROW—goal, reality, options, way forward H1493 Ramu_p00i-284.indd 213 7/13/16 5:56 PM 214 Part VI: Appendices GRPI—goals, roles, processes, interpersonal GRR—gage repeatability and reproducibility GQTS—global quality tracking system GSQA—government source quality assurance GUM—Guide to the Expression of Uncertainty of Measurement Ha—alternative hypothesis HA—hazard analysis HACCP—hazard analysis and critical control points HALT—highly accelerated life test HARM—high-availability, reliability, and maintainability HASA—highly accelerated stress audits HASS—highly accelerated stress screening HAZOP—hazard and operability study HOQ—house of quality HPT—human performance technology HQS—high-quality screening HR—human resources HRM—human resources management HSEQ—health safety environmental quality HSPD—handling, storage, packaging, and delivery HSSE—health safety security environment HSSEQ—health safety security environment quality IABLS—Institute of Advanced Business Learning Systems IAQG—International Aerospace Quality Group IATF—International Automotive Task Force ICOV—identify–characterize–optimize–validate ICT—information communication technology ID—interrelationship digraph IDDOV—identify–define–develop–optimize–verify (and validate) IDEA—identify–design–evaluate–affirm IDOV—identify–design–optimize–verify (and validate) IEC—International Electrotechnical Commission H1493 Ramu_p00i-284.indd 214 7/13/16 5:56 PM Appendix I: Acronym List 215 IEEE—Institute of Electrical and Electronics Engineers IID—independent identically distributed IIE—Institute of Industrial Engineers ILT—instructor lead training IMDS—International Material Data System IMR—individuals and moving range INT—interaction IOBA—International Automotive Oversight Bureau IPIP—improving performance in practice IPO—input–process–output IPS—innovative problem solving IQA—Institute for Quality Assurance IQCS—in-service quality control system IQF—International Quality Federation IQR—interquartile range IQUE—in-plant quality evaluation IRCA—International Register of Certified Auditors IRR—internal rate of return ISD—instructional system design ISIR—Initial Sample Inspection Report ISO—International Organization for Standardization ISPI—International Society for Performance Improvement ISSSP—International Society of Six Sigma Practitioners IT—industrial technology IT—information technology (computers) IT—instructional technology (education) ITU—International Telecommunication Union JCAHO—Joint Commission on Accreditation of Healthcare Organizations JDP—J. D. Power and Associates JIS—Japan Industrial Standard JIT—just in time JUSE—Union of Japanese Scientists and Engineers H1493 Ramu_p00i-284.indd 215 7/13/16 5:56 PM 216 Part VI: Appendices KBC—knowledge based community KBF—key business factors KBI—key business issue KBR—key business requirement KC—key characteristic KCC—key control characteristic KISS—keep it simple and specific or keep it simple statistician KLT—key life test KPC—key product characteristic KPI—key performance indicator KPI—key process indicator KPIV—key process input variable KPOV—key process output variable KSN—knowledge sharing network LACL—lower acceptance control limit LCI—learner controlled instruction LCL—lower control limit LEO—listen (observe and understand), enrich (explore and discover), and optimize (improve and perfect) LIFO—last in, first out LLL—lower lot limit LMS—learning management system LOTO—lock out tag out LQ—limiting quality LQIP—laboratory quality improvement program LQL—limiting quality level LRU—line replaceable unit LSA—logistic support analysis LSD—least significant difference LSL—lower specification limit LSS—Lean Six Sigma LTI—lost time injury H1493 Ramu_p00i-284.indd 216 7/13/16 5:56 PM Appendix I: Acronym List 217 LTPD—lot tolerance percentage defective LTR—long-term return rate m—mean M&A—manufacturing and assembly M&TE—measurement and test equipment MAIC—measure, analyze, improve, and control MAR—maximum allowable range MBB—Master Black Belt MBO—management by objectives MBNQA—Malcolm Baldrige National Quality Award MBTI—Myers-Briggs Type Indicator MBWA—management by walking around MCF—mean cumulative function MDR—Medical Device Report MEDIC—map + measure, explore + evaluate, define + describe, implement + improve, control + conform MFMEA—machinery failure mode and effects analysis MIL-STD—United States military standard MIS—management information systems MIS—months in service MMBF—mean miles between failures MODAPTS—modular arrangement of predetermined time standards MOS—management operating system MOT—moment of truth MPS—master production schedule MQT—maintainability qualification test MRA—mutual recognition arrangements MRB—management review board MRP—material requirements planning MS—mean squares MS (RES)—residual mean square MSA—measurement systems analysis H1493 Ramu_p00i-284.indd 217 7/13/16 5:56 PM 218 Part VI: Appendices MSB—mean square between treatments MSD—maximum standard deviation MSDS—Material Data Safety Sheet MSE—mean squared error MSI—mean square for interaction MSW—mean square within treatments MT&E—measuring tools and equipment MTBF—mean time between failures MTC—manage the change MTTF—mean time to failure MTTN—mean time to notification MTTR—mean time to recover MTTR—mean time to repair NA—needs assessment NA or N/A—not applicable NACCB—National Accreditation Council for Certification

Bodies NADCAP—National Aerospace and Defense Contractors Accreditation Program NATO—North Atlantic Treaty Organization NCT—nonconformance ticket ndc—number of distinct categories NDE—nondestructive evaluation NDT—nondestructive testing NE or N/E—not evaluated NGT—nominal group technique NIH—not invented here NIST—United States National Institute of Standards and Technology NM—near miss incident NMQAO—Naval Materiel Quality Assessment Office NPI—new product introduction NPR—number of problem reports NPV—net present value NQCC—network quality control center H1493 Ramu_p00i-284.indd 218 7/13/16 5:56 PM Appendix I: Acronym List 219 NTF—no trouble found NTRM—NIST Traceable Reference Material NVA—non-value-added NVA-r—non-value-added, but unavoidable NVH—noise, vibration and harshness O—occurrence OBS—observation OC—operating characteristic curve OCAP—out-of-control action plan OCC—operating committee meeting OCM—organizational change management OCT—operations cost target OD—organization development OE—organizational excellence OEE—overall equipment effectiveness OEM—original equipment manufacturer OFI—opportunity for improvement OFM—outage frequency measurement OFR—overdue fix responsiveness OHS—occupational health and safety OJT—on-the-job training OLE—overall labor effectiveness ORT—ongoing reliability test OSHA—United States Occupational Safety and Health Administration OSS—operational support system OTD—on-time delivery OTD—one touch exchange of dies OTI—on-time item delivery OTIS—on-time installed system delivery OTS—on-time service delivery P&L—profit and loss H1493 Ramu_p00i-284.indd 219 7/13/16 5:56 PM 220 Part VI: Appendices P&S—products and services P/T—precision/tolerance PA—patents at risk PAR—preventive action request PART—program assessment rating tool PAT—part average testing PBC—process behavior charts PBIB—partially balanced incomplete block design PC—physical contradiction PCD—process control document PCR—product change request PDA—personal data assistant PDCD—product development cycle PDCA—plan-do-check-act PDM—precedence diagram method PDPC—process decision program chart PDSA—plan-do-study-act PE—professional engineer PERT—program evaluation review technique PFMEA—process failure mode and effects analysis PI—principal inspector PIPC—percent indices which are process capable PISMOEA—part, instrument, standard, method, operator, environment, assumptions PIST—percentage of inspection points satisfying tolerance PIT—process improvement team PM—preventive maintenance PM—program management PMA—premarket approval PMA—president's management agenda PMP—project management professional H1493 Ramu_p00i-284.indd 220 7/13/16 5:56 PM Appendix I: Acronym List 221 PMS—planned maintenance system PMTS—predetermined motion time system PO—purchase order PONC—price of nonconformance Pp—long-term process capability measurement Ppk—long-term process capability measurement ppm—parts per million PPPPPP—proper planning prevents piss-poor performance PPS—production preparation schedule PQ—process qualification PQA—President's Quality Award Pr—capability performance ratios PR—production release PRAT—production reliability acceptance test PRR—problem reporting and resolution or product problem reporting PSO—process sign-off PSP—product support plan PSW—part submission warrant PTC—pass through characteristics PTN—plant test number PUMA—product usage measurements and applications PV—part variation PVP&R—production validation plan and report PYP—pass yield rate H1493 Ramu_p00i-284.indd 221 7/13/16 5:56 PM 222 Part VI: Appendices Q&P—quality and productivity Q&R—quality and reliability QA—quality assurance QA—quality audit QAA—quality assurance action QAA—quality assurance assessment QAA—quality assurance audit QAC—quality assurance checklist QAC—quality assurance committee QAD—quality assurance directorate QAD—quality audit division QADR—quality assurance discrepancy report QAE—quality assurance engineer QAE—quality assurance evaluation QAE—quality assurance executive QAER—quality acceptance equipment release QAF—quality achievement factor QAF—quality assurance fixture QAF—quality assurance form QAHB—Quality Assurance Program Handbook QAI—quality assessment index QAI—Quality Assurance Institute QAI—quality assurance instruction QALI—quality assurance letter of instruction QAM—quality assurance manager QAM—quality assurance manual QAN—quality action notice QAP—quality assurance plan QAP—quality assurance program QAPI—quality assurance program index QAPR—Quality Army Performance Review QAR—quality acceptance report QAR—quality assurance representative QAR—quality assurance and reliability QAR—quality assurance requirement H1493 Ramu_p00i-284.indd 222 7/13/16 5:56 PM Appendix I: Acronym List 223 QAR—quality assurance requirements QAR—quality assurance review QAR—quantitative analysis report QAS—quality assurance specialist QAS—quality assurance standard QAS—quality assurance surveillance QASP—quality assurance support plan QATAP—quality assurance through attributes program QATP—quality assurance technical development program QBP—quality and business planning QC—quality center QC—quality control QC—quality circle QC—quality counselor QCB—quality control board QCC—quality control circle QCD—quality, cost, and delivery QCI—quality control inspection QCI—quality control instruction QCM—quality control monitoring QCM—quality control management QCP—quality commitment performance H1493 Ramu_p00i-284.indd 223 7/13/16 5:56 PM 224 Part VI: Appendices QCP—quality control program QCR—quality control reliability QCR—quality control representative QCS—quality and customer satisfaction QCS—quality control system QCT—quality, cost, time QCWT—quality, cost, weight, and time QDR—quality, durability, reliability QDR—quality deficiency report(s) QEMS—quality and environmental management system QEP—quality enhancement program QEP—quality evaluation program QF—quality form QFD—quality function deployment QIS—quality information system QIT—quality improvement team QITQM—Quality Improvement Total Quality Management (magazine) QLA—quality level agreement H1493 Ramu_p00i-284.indd 224 7/13/16 5:56 PM Appendix I: Acronym List 225 QLF—quality loss function QMAS—Quality Measurement Advisory Service QMIS—quality management information system QMP—quality manufacturing and purchasing QMS—quality management system QOS—quality of service QOS—quality operating system QP—quality procedure QPC—quality and process control QPI—quality performance indicator QPM—quality and productivity management QPM—quality performance management QPM—quality performance measurement QPM—quality program manager QPS—quality planning sheets QPS—quality process sheets QR—quality and reliability QR—quality requirement QR—quality record QRA—quality and reliability assurance QRA—quality risk assessment QRA—quick reaction assessment QRA—quick readiness assessment H1493 Ramu_p00i-284.indd 225 7/13/16 5:56 PM 226 Part VI: Appendices QRB—quality review board QRC—quality record coordinator QRC—quality risk and cost QRT—quality response team QS—quality systems QS-9000—Quality System Requirements 9000 QSA—quality system assessment QSDC—quality systems document coordinator QSHC—Quality and Safety in Health Care (magazine) QSP—quality strategy and planning QSR—quality system requirements QSU—quality system update QTS—quality tracking study QuASAR—Quality And Safety Achievement Recognition QUEST—quality electrical systems test QUEST—quality evaluation of settlement QUEST—Quality Excellence for Suppliers of Telecommunications QUICS—quality utilization generic screens QUIP—quality assessment and improvement program QUIP—quality assurance inspection procedure QUIT—Quality in Training QVI—quality verification inspection H1493 Ramu_p00i-284.indd 226 7/13/16 5:56 PM Appendix I: Acronym List 227 QVP—quality verification process R—range R^2—coefficient of determination R2R—runs to reject R&A—reliability and availability R&D—research and development R&M—reliability and maintainability R&MWG—reliability and maintainability working group R&R—repeatability and reproducibility (see also GR&R) RA—risk analysis RA—risk assessment RAB—registrar accreditation board RABQSA—RABQSA International (formerly the Registrar Accreditation Board and the Quality Society of Australasia) RADHAZ—radio and radar radiation hazards RAM—reliability, availability, and maintainability RAMS—reliability, availability, maintainability, and safety RAMSH—reliability, availability, maintainability, safety, and human factors (engineering) RAMTIP—Reliability and Maintainability Technology Insertion Program RAPID—rapid actions for process improvement deployment RAS—reliability, availability, and serviceability RBD—reliability block diagram RBI—risk based inspection RBM—risk based maintenance RCA—root cause analysis H1493 Ramu_p00i-284.indd 227 7/13/16 5:56 PM 228 Part VI: Appendices RCE—robustness checklist RCM—reliability centered maintenance RDGT—reliability development/growth test RDCOV—recognize-define-characterize-optimize-verify REG—regression REM—reliability engineering model RES—residual RF—radio frequency RF—remaining float RFI—radio frequency interference RFP—request for proposal RFQ—request for quote RFTA—reverse fault tree analysis RII—required inspection item RIW—reliability improvement warranty RM—reference material RM&A—reliability, maintainability, and availability RM&S—reliability, maintainability, and supportability RMMP—reliability and maintainability management plan RMS—root mean square ROA—return on assets ROI—return on investment ROM—rough order of magnitude RONA—return on net assets RPL—rejectable process level RPN—risk priority number RQL—rejectable quality level RQMS—Reliability and Quality Measurements for Telecommunications Systems H1493 Ramu_p00i-284.indd 228 7/13/16 5:56 PM Appendix I: Acronym List 229 RQT—reliability qualification test(ing) RRA—residual risk assessment RSM—repair station manual RSM—response surface methodology RSS—root sum of squares RTY—rolled throughput yield S—severity S/S—safety and suitability for service SAE—Society of Automotive Engineers or SAE International SB—service bulletin SBP—strategic business plan SC—significant characteristic SCOT—strengths, challenges, opportunities, threats SCP—service control point SDCA—standardize-do-check-act SDE—supplier development engineer SDS—safety data sheet SDWT—self-directed work team SE—simultaneous engineering SET—senior executive team SF—secondary float SIPOC—supplier, input, process, output, and customer SIT—systematic inventive thinking SKSP—skip-lot sampling plan SLACK—summary, learning objectives, application, context, knowledge base SMART—specific, meaningful, agreed to, realistic, time-based SMARTER—specific, measurable, acceptable, realistic, time-bound, evaluated, reviewed SME—Society of Manufacturing Engineers H1493 Ramu_p00i-284.indd 229 7/13/16 5:56 PM 230 Part VI: Appendices SME—small and medium enterprises SME—subject matter expert SMED—single-minute exchange of die SMS—safety management system SN—signal-to-noise ratio SO—system outage measurement SOP—standard operating procedure SoPK—System of Profound Knowledge (Dr. W. Edwards Deming) SOR—sign-off report SOW—statement of work SPA—second party audit SPC—statistical process control SPD—statistical process design SPOF—single point of failure SPOT—scope, purpose, overview, tangible benefits SQC—statistical quality control SQDCME—safety, quality, delivery, cost, moral, environment SQE—software quality evaluation SQE—supplier quality engineer SQI—supplier quality improvement SQIP—strategic quality plan SQR—supplier quality representative SQRTF—Supplier Quality Requirements Task Force SREA—supplier request for engineering approval SRG—statistical research group SRM—supplier relationship management SRMR—security risk management review SS—Six Sigma H1493 Ramu_p00i-284.indd 230 7/13/16 5:56 PM Appendix I: Acronym List 231 SS—sum of squares SSB—between-treatments sum of squares SSBB—Six Sigma Black Belt SSBoK—Six Sigma Body of Knowledge SSC—column sum of squares SSE—error sum of squares SSGB—Six Sigma Green Belt SSI—interaction sum of squares SSMBB—Six Sigma Master Black Belt SSOS—Six Sigma operating system SSR—row sum of squares SSRA—system safety risk assessment SST—total sum of squares SSW—within-treatments sum of squares SSYB—Six Sigma Yellow Belt STA—supplier technical assistance STD—standard deviation STOP—Safety Training Observation Program STS—synchronous transport signal SWAG—statistical wild ass guess SWIPE—standard, workpiece, instrument, person and procedure, environment SWOT—strengths, weaknesses, opportunities, threats T—target T&E—test and evaluation T&EO—training and evaluation outline T&M—time and materials T&O—test and operation H1493 Ramu_p00i-284.indd 231 7/13/16 5:56 PM 232 Part VI: Appendices TAG—technical advisory group TBD—to be determined TBE—to be established TC—technical committee TF—total float TGR—things gone right TGW—things gone wrong TMAP—thought process map TNA—training needs assessment TOC—theory of constraints TOPS—total operational performance system TOU—terms of use TPA—third-party audit TPM—total productive maintenance TPS—Toyota Production System TQ—total quality TQC—total quality control TQHRM—total quality human resources management TQM—total quality management TRACE—total risk assessment cost estimate TRIZ—theory of inventive problem solving TS—technical specification TSS—total sum of squares TV—total variation TVM—total value management TWI—training within industry H1493 Ramu_p00i-284.indd 232 7/13/16 5:56 PM Appendix I: Acronym List 233 UCL—upper control limit UKAS—United Kingdom Accreditation Service ULL—upper lot limit UP—unit price UPC—uniform parts code UQL—unacceptable quality level USL—upper specification limit VA—value-added VA/VE—value analysis/value engineering VC—virtual container VDA—Verband der Automobilindustrie (German) VIM—International Vocabulary of Metrology—Basic and General Concepts and Associated Terms VIN—vehicle identification number VIPER—verifiable integrated processor for enhanced reliability VOB—voice of the business VOC—voice of the customer VOE—voice of the employee VOP—voice of the process VQD—visual quality document VSAS—vehicle situational awareness system VSM—value stream mapping WAG—wild ass guess WBS—work breakdown structure WCS—worst case scenario WI—work instructions WIIFM—what's in it for me WIP—work in process WOW—worst of the worst WQP—worldwide quality procedures WQS—worldwide quality standards H1493 Ramu_p00i-284.indd 233 7/13/16 5:56 PM 234 Part VI: Appendices WYSIWYG—What you see is what you get x—average X—cause or process variable Y—effect or process output YRR—one-year return rate ZD—zero defects H1493 Ramu_p00i-284.indd 234 7/13/16 5:56 PM

Glossary A acceptance quality limit (AQL)—The quality level that is the worst tolerable product average when a continuing series of lots is submitted for acceptance sampling. acceptance number—The maximum number of defects or defectives allowable in a sampling lot for the lot to be acceptable. acceptance sampling—Inspection of a sample from a lot to decide whether to accept that lot. There are two types: attributes sampling and variables sampling. In attributes sampling, the presence or absence of a characteristic is noted in each of the units inspected. In variables sampling, the numerical magnitude of a characteristic is measured and recorded for each inspected unit; this involves reference to a continuous scale of some kind. acceptance sampling plan—A specific plan that indicates the sampling sizes and associated acceptance or nonacceptance criteria to be used. In attributes sampling, for example, there are single, double, multiple, sequential, chain, and skip-lot sampling plans. In variables sampling, there are single, double, and sequential sampling plans. For detailed descriptions of these plans, see the standard ANSI/ISO/ASQ A3534-2-1993: Statistics—Vocabulary and symbols—Statistical quality control. accuracy—The closeness of agreement between a test result or measurement result and the accepted/true value.2 activity based costing—An accounting system that assigns costs to a product based on the amount of resources used to design, order, or make it. activity network diagram—A diagram that links tasks with direct arrows showing the path through the task list. Tasks are linked when a task is dependent on a preceding task.3 (AKA arrow diagram.) Advanced Product Quality Planning (APQP)—High-level automotive process for product realization, from design through production part approval. affinity diagram—A management tool for organizing information (usually gathered during a brainstorming activity). 235 H1493 Ramu_p00i-284.indd 235 7/13/16 5:56 PM 236 Glossary American National Standards Institute (ANSI)—A private, nonprofit organization that administers and coordinates the U.S. voluntary standardization and conformity assessment system. It is the U.S. member body in the International Organization for Standardization, known as ISO. American Society for Quality (ASQ)—A global community of people dedicated to quality who share the ideas and tools that make our world work better. With individual and organizational members around the world, ASQ has the reputation and reach to bring together the diverse quality champions who are transforming the world's corporations, organizations, and communities to meet tomorrow's critical challenges. analysis of means (ANOM)—A statistical procedure for troubleshooting industrial processes and analyzing the results of experimental designs with factors at fixed levels. It provides a graphical display of data. Ellis R. Ott developed the procedure in 1967 because he observed that nonstatisticians had difficulty understanding analysis of variance. Analysis of means is easier for quality practitioners to use because it is an extension of the control chart. In 1973, Edward G. Schilling further extended the concept, enabling analysis of means to be used with nonnormal distributions and attributes data in which the normal approximation to the binomial distribution does not apply. This is referred to as analysis of means for treatment effects. analysis of variance (ANOVA)—A basic statistical technique for determining the proportion of influence a factor or set of factors has on total variation. It subdivides the total variation of a data set into meaningful component parts associated with specific sources of variation to test a hypothesis on the parameters of the model or to estimate variance components. There are three models: fixed, random, and mixed. analytical (inferential) studies—A set of techniques used to arrive at a conclusion about a population based upon the information contained in a sample taken from that population.1 arrow diagram—A planning tool used to diagram a sequence of events or activities (nodes) and their interconnectivity. It is used for scheduling and especially for determining the critical path through nodes. (AKA activity network diagram.) assignable cause—A name for the source of variation in a process that is not due to chance and therefore can be identified and eliminated. Also called "special cause." attributes (discrete) data—Go/no-go information. The control charts based on attributes data include percent chart, number of affected units chart, count chart, count per unit chart, quality score chart, and demerit chart. attributes, method of—Method of measuring quality that consists of noting the presence (or absence) of some characteristic (attribute) in each of the units under consideration and counting how many units do (or do not) possess it. Example: go/no-go gauging of a dimension. audit—The on-site verification activity, such as inspection or examination, of a product, process, or quality system, to ensure compliance to requirements. H1493 Ramu_p00i-284.indd 236 7/13/16 5:56 PM Glossary 237 An audit can apply to an entire organization or might be specific to a function, process, or production step. Automotive Industry Action Group (AIAG)—A global automotive trade association with about 1600 member companies that focuses on common business processes, implementation guidelines, education, and training. average chart—A control chart in which the subgroup average, x-, is used to evaluate the stability of the process level. average outgoing quality (AOQ)—The expected average quality level of an outgoing product for a given value of incoming product quality. average outgoing quality limit (AOQL)—The maximum average outgoing quality over all possible levels of incoming quality for a given acceptance sampling plan and disposal specification. average run length (ARL)—On a control chart, the number of subgroups expected to be inspected before a shift in magnitude takes place. average sample number (ASN)—The average number of sample units inspected per lot when reaching decisions to accept or reject. average total inspection (ATI)—The average number of units inspected per lot, including all units in rejected lots. Applicable when the procedure calls for 100 percent inspection of rejected lots. B balanced scorecard—A management system that provides feedback on both internal business processes and external outcomes to continuously improve strategic performance and results. Baldrige Award—See Malcolm Baldrige National Quality Award. baseline measurement—The beginning point, based on an evaluation of output over a period of time, used to determine the process parameters prior to any improvement effort; the basis against which change is measured. batch and queue—Producing more than one piece and then moving the pieces to the next operation before they are needed. Bayes's theorem—A formula to calculate conditional probabilities by relating the conditional and marginal probability distributions of random variables. benchmarking—A technique in which a company measures its performance against that of best-in-class companies, determines how those companies achieved their performance levels, and uses the information to improve its own performance. Subjects that can be benchmarked include strategies, operations, and processes. benefit–cost analysis—An examination of the relationship between the monetary cost of implementing an improvement and the monetary value of the benefits achieved by the improvement, both within the same time period. H1493 Ramu_p00i-284.indd 237 7/13/16 5:56 PM 238 Glossary bias—The influence in a sample of a factor that causes the data population or process being sampled to appear different from what it actually is, typically in a specific direction.1 binomial distribution—A discrete distribution that is applicable whenever an experiment consists of n independent Bernoulli trials and the probability of an outcome, say, success, is constant throughout the experiment.1 Black Belt (BB)—Full-time team leader responsible for implementing process improvement projects—define, measure, analyze, improve, and control (DMAIC) or define, measure, analyze, design, and verify (DMADV)—within a business to drive up customer satisfaction and productivity levels. block diagram—A diagram that shows the operation, interrelationships, and interdependencies of components in a system. Boxes, or blocks (hence the name), represent the components; connecting lines between the blocks represent interfaces. There are two types of block diagrams: a functional block diagram, which shows a system's subsystems and lower-level products and their interrelationships and which interfaces with other systems; and a reliability block diagram, which is similar to the functional block diagram but is modified to emphasize those aspects influencing reliability. brainstorming—A technique teams use to generate ideas on a particular subject. Each person on the team is asked to think creatively and write down as many ideas as possible. The ideas are not discussed or reviewed until after the brainstorming session. breakthrough improvement—A dynamic, decisive movement to a new, higher level of performance. business process reengineering (BPR)—The concentration on improving business processes to deliver outputs that will achieve results meeting the firm's objectives, priorities, and mission. C calibration—The comparison of a measurement instrument or system of unverified accuracy to a measurement instrument or system of known accuracy to detect any variation from the required performance specification. capability—The total range of inherent variation in a stable process determined by using data from control charts. causation—The relationship between two variables. The changes in variable x cause changes in y. For example, a change in outdoor temperature causes changes in natural gas consumption for heating. If we can change x, we can bring about a change in y. cause—An identified reason for the presence of a defect, problem, or effect. cause-and-effect diagram—A tool for analyzing process dispersion. It is also referred to as the "Ishikawa diagram," because Kaoru Ishikawa developed it, H1493 Ramu_p00i-284.indd 238 7/13/16 5:56 PM Glossary 239 and the "fishbone diagram," because the complete diagram resembles a fish skeleton. The diagram illustrates the main causes and subcauses leading to an effect (symptom). The cause-and-effect diagram is one of the "seven tools of quality." c-chart—See count chart. central line—A line on a graph that represents the overall average (mean) operating level of the process. central limit theorem—A theorem that states that irrespective of the shape of the distribution of a population, the distribution of sample means is approximately normal when the sample size is large.1 central tendency—The tendency of data gathered from a process to cluster toward a middle value somewhere between the high and low values of measurement. certification—The result of a person meeting the established criteria set by a certificate granting organization. Certified Six Sigma Black Belt (CSSBB)—An ASQ certification. Certified Six Sigma Green Belt (CSSGB)—An ASQ certification. chain reaction—A chain of events described by W. Edwards Deming: improve quality, decrease costs, improve productivity, increase market share with better quality and lower price, stay in business, provide jobs, and provide more jobs. chain sampling plan—In acceptance sampling, a plan in which the criteria for acceptance and rejection apply to the cumulative sampling results for the current lot and one or more immediately preceding lots. champion—A business leader or senior manager who ensures that resources are available for training and projects, and who is involved in periodic project reviews; also an executive who supports and addresses Six Sigma organizational issues. change agent—An individual from within or outside an organization who facilitates change in the organization; might be the initiator of the change effort, but not necessarily. changeover—A process in which a production device is assigned to perform a different operation or a machine is set up to make a different part—for example, a new plastic resin and new mold in an injection molding machine. changeover time—The time required to modify a system or workstation, usually including both teardown time for the existing condition and setup time for the new condition. characteristic—The factors, elements, or measures that define and differentiate a process, function, product, service, or other entity. chart—A tool for organizing, summarizing, and depicting data in graphic form. H1493 Ramu_p00i-284.indd 239 7/13/16 5:56 PM 240 Glossary charter—A written commitment approved by management stating the scope of authority for an improvement project or team. check sheet—A simple data recording device. The check sheet is custom designed by the user, which allows him or her to readily interpret the results. The check sheet is one of the "seven tools of quality." checklist—A tool for ensuring that all important steps or actions in an operation have been taken. Checklists contain items important or relevant to an issue or situation. Checklists are often confused with check sheets. chi square distribution—Probability distribution of sum of squares of n independent normal variables.1 classification of defects—The listing of possible defects of a unit, classified according to their seriousness. Note: Commonly used classifications: class A, class B, class C, class D; or critical, major, minor, and incidental; or critical, major, and minor. Definitions of these classifications require careful preparation and tailoring to the product(s) being sampled to ensure accurate assignment of a defect to the proper classification. A separate acceptance sampling plan is generally applied to each class of defects. common causes—Causes of variation that are inherent in a process over time. They affect every outcome of the process and everyone working in the process. (AKA chance causes.) Also see special causes. compliance—The state of an organization that meets prescribed specifications, contract terms, regulations, or standards. conformance—An affirmative indication or judgment that a product or service has met the requirements of a relevant specification, contract, or regulation. conformity assessment—All activities concerned with determining that relevant requirements in standards or regulations are fulfilled, including sampling, testing, inspection, certification, management system assessment and registration, accreditation of the competence of those activities, and recognition of an accreditation program's capability. constraint—Anything that limits a system from achieving higher performance or throughput; also, the bottleneck that most severely limits the organization's ability to achieve higher performance relative to its purpose or goal. consumer—The external customer to whom a product or service is ultimately delivered; also called end user. continuous (variables) data—Data that vary with discontinuity across an interval. The values of continuous data are often represented by floating point numbers. In sampling, continuous data are often referred to as variables data.3 continuous flow production—A method in which items are produced and moved from one processing step to the next, one piece at a time. Each process makes only the one piece that the next process needs, and the transfer batch size is one. Also referred to as one-piece flow and single-piece flow. H1493 Ramu_p00i-284.indd 240 7/13/16 5:56 PM Glossary 241 continuous improvement (CI)—Sometimes called continual improvement. The ongoing improvement of products, services, or processes through incremental and breakthrough improvements. continuous quality improvement (CQI)—A philosophy and attitude for analyzing capabilities and processes and improving them repeatedly to achieve customer satisfaction. continuous sampling plan—In acceptance sampling, a plan, intended for application to a continuous flow of individual units of product, that involves acceptance and rejection on a unit-by-unit basis and employs alternate periods of 100 percent inspection and sampling. The relative amount of 100 percent inspection depends on the quality of submitted product. Continuous sampling plans usually require that each t period of 100 percent inspection be continued until a specified number i of consecutively inspected units is found clear of defects. Note: For single-level continuous sampling plans, a single d sampling rate (for example, inspect one unit in five or one unit in 10) is used during sampling. For multilevel continuous sampling plans, two or more sampling rates can be used. The rate at any given time depends on the quality of submitted product. control chart—A chart with upper and lower control limits on which values of some statistical measure for a series of samples or subgroups are plotted. The chart frequently shows a central line to help detect a trend of plotted values toward either control limit. control limits—The natural boundaries of a process within specified confidence levels, expressed as the upper control limit (UCL) and the lower control limit (LCL). control plan (CP)—Written description of the systems for controlling part and process quality by addressing the key characteristics and engineering requirements. corrective action—A solution meant to reduce or eliminate an identified problem. corrective action recommendation (CAR)—The full cycle corrective action tool that offers ease and simplicity for employee involvement in the corrective action/process improvement cycle. correlation (statistical)—A measure of the relationship between two data sets of variables. cost of poor quality (COPQ)—The costs associated with providing poor-quality products or services. There are four categories: internal failure costs (costs associated with defects found before the customer receives the product or service), external failure costs (costs associated with defects found after the customer receives the product or service), appraisal costs (costs incurred to determine the degree of conformance to quality requirements), and prevention costs (costs incurred to keep failure and appraisal costs to a minimum). H1493 Ramu_p00i-284.indd 241 7/13/16 5:56 PM 242 Glossary cost of quality (COQ)—Another term for COPQ. It is considered by some to be synonymous with COPQ but is considered by others to be unique. While the two concepts emphasize the same ideas, some disagree as to which concept came first and which categories are included in each. count chart—A control chart for evaluating the stability of a process in terms of the count of events of a given classification occurring in a sample; known as a "c-chart." count per unit chart—A control chart for evaluating the stability of a process in terms of the average count of events of a given classification per unit occurring in a sample. Cp—The ratio of tolerance to six sigma, or the upper specification limit (USL) minus the lower specification limit (LSL) divided by six sigma. It is sometimes referred to as the engineering tolerance divided by the natural tolerance and is only a measure of dispersion. Cpk index—Equals the lesser of the USL minus the mean divided by three sigma (or the mean) minus the LSL divided by three sigma. The greater the Cpk value, the better. Cpm—Used when a target value within the specification limits is more significant than overall centering.3 critical path method (CPM)—An activity-oriented project management technique that uses arrow-diagramming techniques to demonstrate both the time and the cost required to complete a project. It provides one time estimate: normal time. critical to quality (CTQ)—A characteristic of a product or service that is essential to ensure customer satisfaction.2 cumulative sum control chart (CUSUM)—A control chart on which the plotted value is the cumulative sum of deviations of successive samples from a target value. The ordinate of each plotted point represents the algebraic sum of the previous ordinate and the most recent deviations from the target. customer relationship management (CRM)—A strategy for learning more about customers' needs and behaviors to develop stronger relationships with them. It brings together information about customers, sales, marketing effectiveness, responsiveness, and market trends. It helps businesses use technology and human resources to gain insight into the behavior of customers and the value of those customers. customer satisfaction—The result of delivering a product or service that meets customer requirements. cycle time—The time required to complete one cycle of an operation. If cycle time for every operation in a complete process can be reduced to equal takt time, products can be made in single-piece flow. Also see takt time. cyclical variation—Looks at the piece-to-piece changes in consecutive order. Patterns are identified in groups, batches, or lots of units.3 H1493 Ramu_p00i-284.indd 242 7/13/16 5:56 PM Glossary 243 D data—A set of collected facts. There are two basic kinds of numerical data: measured or variables data, such as "16 ounces," "4 miles," and "0.75 inches," and counted or attributes data, such as "go/no go" or "yes/no." D-chart—See demerit chart. decision matrix—A matrix teams use to evaluate problems or possible solutions. For example, a team might draw a matrix to evaluate possible solutions, listing them in the far left vertical column. Next, the team selects criteria to rate the possible solutions, writing them across the top row. Then, each possible solution is rated on a scale of 1 to 5 for each criterion, and the rating is recorded in the corresponding grid. Finally, the ratings of all the criteria for each possible solution are added to determine its total score. The total score is then used to help decide which solution deserves the most attention. defect—A product's or service's nonfulfillment of an intended requirement or reasonable expectation for use, including safety considerations. There are four classes of defects: class 1, very serious, leads directly to severe injury or catastrophic economic loss; class 2, serious, leads directly to significant injury or significant economic loss; class 3, major, is related to major problems with respect to intended normal or reasonably foreseeable use; and class 4, minor, is related to minor problems with respect to intended normal or reasonably foreseeable use. defective—A defective unit; a unit of product that contains one or more defects with respect to the quality characteristic(s) under consideration. demerit chart—A control chart for evaluating a process in terms of a demerit (or quality score); in other words, a weighted sum of counts of various classified nonconformities. Deming cycle—Another term for the plan–do–study–act cycle. Walter Shewhart created it (calling it the plan–do–check–act cycle), but W. Edwards Deming popularized it, calling it plan–do–study–act. dependability—The degree to which a product is operable and capable of performing its required function at any randomly chosen time during its specified operating time, provided that the product is available at the start of that period. (Nonoperation related influences are not included.) Dependability can be expressed by the following ratio: time available divided by (time available + time required). design for Six Sigma (DFSS)—Used for developing a new product or process, or for processes that need total overhaul. A process often used in DFSS is called DMADV: define, measure, analyze, design, verify.4 See also DMADV. design of experiments (DOE)—A branch of applied statistics dealing with planning, conducting, analyzing, and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters. H1493 Ramu_p00i-284.indd 243 7/13/16 5:56 PM 244 Glossary design record—Engineering requirements, typically contained in various formats; examples include engineering drawings, math data, and referenced specifications. detection—The likelihood the failure will be caught by the current controls before it gets to the customer (usually a scale of 1-5 or 1-10). deviation—In numerical data sets, the difference or distance of an individual observation or data value from the center point (often the mean) of the set distribution. dissatisfiers—The features or functions a customer expects that either are not present or are present but not adequate; also pertains to employees' expectations. distribution (statistical)—The amount of potential variation in the outputs of a process, typically expressed by its shape, average, or standard deviation. DMADV—A data-driven quality strategy for designing products and processes; it is an integral part of a Six Sigma quality initiative. It consists of five interconnected phases: define, measure, analyze, design, and verify. DMAIC—A data-driven quality strategy for improving processes, and an integral part of a Six Sigma quality initiative. DMAIC is an acronym for define, measure, analyze, improve, and control. Dodge-Romig sampling plans—Plans for acceptance sampling developed by Harold F. Dodge and Harry G. Romig. Four sets of tables were published in 1940: single sampling lot tolerance tables, double sampling lot tolerance tables, single sampling average outgoing quality limit tables, and double sampling average outgoing quality limit tables. downtime—Lost production time during which a piece of equipment is not operating correctly due to breakdown, maintenance, power failures, or similar events. E effect—The result of an action being taken; the expected or predicted impact when an action is to be taken or is proposed. effectiveness—The state of having produced a decided on or desired effect. efficiency—The ratio of the output to the total input in a process. efficient—A term describing a process that operates effectively while consuming minimal resources (such as labor and time). eight wastes—Taiichi Ohno originally enumerated seven wastes (muda) and later added underutilized people as the eighth waste commonly found in physical production. The eight are (1) overproduction ahead of demand, (2) waiting for the next process, worker, material, or equipment, (3) unnecessary transport of materials (for example, between functional areas of facilities, or to or from a stockroom or warehouse), (4) overprocessing of parts due to poor tool and product design, (5) inventories more than the absolute minimum, (6) H1493 Ramu_p00i-284.indd 244 7/13/16 5:56 PM Glossary 245 unnecessary movement by employees during the course of their work (such as to look for parts, tools, prints, or help), (7) production of defective parts, (8) underutilization of employees' brainpower, skills, experience, and talents. eighty–twenty (80–20)—A term referring to the Pareto principle, which was first defined by J. M. Juran in 1950. The principle suggests that most effects come from relatively few causes; that is, 80 percent of the effects come from 20 percent of the possible causes. Also see Pareto chart. enumerative (descriptive) studies—A group of methods used for organizing, summarizing, and representing data using tables, graphs, and summary statistics.1 error detection—A hybrid form of error-proofing. It means a bad part can be made but will be caught immediately, and corrective action will be taken to prevent another bad part from being produced. A device is used to detect and stop the process when a bad part is made. This is used when error-proofing is too expensive or not easily implemented. error-proofing—Use of process or design features to prevent the acceptance or further processing of nonconforming products. Also known as mistake-proofing. experimental design—A formal plan that details the specifics for conducting an experiment, such as which responses, factors, levels, blocks, treatments, and tools are to be used. external customer—A person or organization that receives a product, service, or information but is not part of the organization supplying it. Also see internal customer. external failure—Nonconformance identified by the external customers. F failure—The inability of an item, product, or service to perform required functions on demand due to one or more defects. failure cost—The cost resulting from the occurrence of defects. One element of cost of quality or cost of poor quality. failure mechanism—Mechanism describing how the cause of the failure mode results in failure. failure mode—Expressed as the inability to achieve the stated function. failure mode analysis (FMA)—A procedure to determine which malfunction symptoms appear immediately before or after a failure of a critical parameter in a system. After all possible causes are listed for each symptom, the product is designed to eliminate the problems. failure mode and effects analysis (FMEA)—A systematized group of activities to recognize and evaluate the potential failure of a product or process and its effects, identify actions that could eliminate or reduce the occurrence of the potential failure, and document the process. H1493 Ramu_p00i-284.indd 245 7/13/16 5:56 PM 246 Glossary F-distribution—A continuous probability distribution of the ratio of two independent chi-square random variables.1 first in, first out (FIFO)—Use of material produced by one process in the same order by the next process. A FIFO queue is filled by the supplying process and emptied by the customer process. When a FIFO lane gets full, production is stopped until the next (internal) customer has used some of that inventory. first-pass yield (FPY)—Also referred to as the quality rate, the percentage of units that completes a process and meets quality guidelines without being scrapped, rerun, retested, returned, or diverted into an offline repair area. FPY is calculated by dividing the units entering the process minus the defective units by the total number of units entering the process. first-time quality (FTQ)—Calculation of the percentage of good parts at the beginning of a production run. fishbone diagram—See cause-and-effect diagram. fitness for use—A term used to indicate that a product or service fits the customer's defined purpose for that product or service. five S (5S)—Five Japanese terms beginning with "s" used to create a workplace suited for visual control and lean production. Seiri means to separate needed tools, parts, and instructions from unneeded materials and to remove the unneeded ones. Seiton means to neatly arrange and identify parts and tools for ease of use. Seiso means to conduct a cleanup campaign. Seiketsu means to conduct seiri, seiton, and seiso daily to maintain a workplace in perfect condition. Shitsuke means to form the habit of always following the first four S's. five whys—A technique for discovering the root causes of a problem and showing the relationship of causes by repeatedly asking the question, "Why?" flow—The progressive achievement of tasks along the value stream so a product proceeds from design to launch, order to delivery, and raw to finished materials in the hands of the customer with no stoppages, scrap, or backflows. flowchart—A graphical representation of the steps in a process. Flowcharts are drawn to better understand processes. One of the "seven tools of quality." force-field analysis—A technique for analyzing what aids or hinders an organization in reaching an objective. An arrow pointing to an objective is drawn down the middle of a piece of paper. The factors that will aid the objective's achievement, called the driving forces, are listed on the left side of the arrow. The factors that will hinder its achievement, called the restraining forces, are listed on the right side of the arrow. G gage repeatability and reproducibility (GR&R)—The evaluation of a gauging instrument's accuracy by determining whether its measurements are repeatable (there is close agreement among a number of consecutive measurements of the output for the same value of the input under the same operating conditions) and reproducible (there is close agreement among repeated H1493 Ramu_p00i-284.indd 246 7/13/16 5:56 PM Glossary 247 measurements of the output for the same value of input made under the same operating conditions over a period of time). Gantt chart—A type of bar chart used in process planning and control to display planned and finished work in relation to time. geometric dimensioning and tolerancing (GD&T)—A set of rules and standard symbols to define part features and relationships on an engineering drawing depicting the geometric relationship of part features and allowing the maximum tolerance that permits full function of the product. go/no-go—State of a unit or product. Two parameters are possible: go (conforms to specifications) and no-go (does not conform to specifications). Green Belt (GB)—An employee who has been trained in the Six Sigma improvement method at a Green Belt level and will lead a process improvement or quality improvement team as part of his or her full-time job. H Hawthorne effect—The concept that every change results (initially, at least) in increased productivity. heijunka—A method of leveling production, usually at the final assembly line, that makes just-in-time production possible. It involves averaging both the volume and sequence of different model types on a mixed-model production line. Using this method avoids excessive batching of different types of product and volume fluctuations in the same product. histogram—A graphic summary of variation in a set of data. The pictorial nature of a histogram lets people see patterns that are difficult to detect in a simple table of numbers. One of the "seven tools of quality." hoshin kanri—The selection of goals, projects to achieve the goals, designation of people and resources for project completion, and establishment of project metrics. hoshin planning—Breakthrough planning. A Japanese strategic planning process in which a company develops up to four vision statements that indicate where the company should be in the next five years. Company goals and work plans are developed based on the vision statements. Periodic submitted audits are then conducted to monitor progress. Also see value stream. house of quality—A product planning matrix, somewhat resembling a house, that is developed during quality function deployment and shows the relationship of customer requirements to the means of achieving these requirements. I in-control process—A process in which the statistical measure being evaluated is in a state of statistical control; in other words, the variations among the observed sampling results can be attributed to a constant system of chance causes (common causes). Also see out-of-control process. H1493 Ramu_p00i-284.indd 247 7/13/16 5:56 PM 248 Glossary incremental improvement—Improvement implemented on a continual basis. indicators—Established measures to determine how well an organization is meeting its customers' needs and other operational and financial performance expectations. inputs—The products, services, and material obtained from suppliers to produce the outputs delivered to customers. inspection—Measuring, examining, testing, and gauging one or more characteristics of a product or service and comparing the results with specified requirements to determine whether conformity is achieved for each characteristic. inspection, normal—Inspection used in accordance with a sampling plan under ordinary circumstances. inspection, 100 percent—Inspection of all the units in the lot or batch. inspection cost—The cost associated with inspecting a product to ensure that it meets the internal or external customer's needs and requirements; an appraisal cost. inspection lot—A collection of similar units or a specific quantity of similar material offered for inspection and acceptance at one time. internal customer—The recipient (person or department) within an organization of another person's or department's output (product, service, or information). Also see external customer. internal failure—A product failure that occurs before the product is delivered to external customers. International Organization for Standardization—A network of national standards institutes from 157 countries working in partnership with international organizations, governments, industry, business, and consumer representatives to develop and publish international standards; acts as a bridge between public and private sectors. interrelationship diagram—A management tool that depicts the relationship among factors in a complex situation; also called a relations diagram. Ishikawa diagram—See cause-and-effect diagram. J jidoka—The deliberate effort to automate a process with a human touch. It means that when a problem occurs on a production line, a worker or machine is able to stop the process and prevent defective goods from being produced. just-in-time (JIT) manufacturing—An optimal material requirement planning system for a manufacturing process in which there is little or no manufacturing material inventory on hand at the manufacturing site and little or no incoming inspection. H1493 Ramu_p00i-284.indd 248 7/13/16 5:56 PM Glossary 249 K kaizen—A Japanese term that means gradual unending improvement by doing little things better and setting and achieving increasingly higher standards. Masaaki Imai made the term famous in his book Kaizen: The Key to Japan's Competitive Success. kanban—A Japanese term for one of the primary tools of a just-in-time system. It maintains an orderly and efficient flow of materials throughout the entire manufacturing process. It is usually a printed card that contains specific information such as part name, description, and quantity. key performance indicator (KPI)—A statistical measure of how well an organization is doing in a particular area. A KPI could measure a company's financial performance or how it is holding up against customer requirements. key process characteristic—A process parameter that can affect safety or compliance with regulations, fit, function, performance, or subsequent processing of product. key product characteristic—A product characteristic that can affect safety or compliance with regulations, fit, function, performance, or subsequent processing of product. L leadership—An essential part of a quality improvement effort. Organization leaders must establish a vision, communicate that vision to those in the organization, and provide the tools and knowledge necessary to accomplish the vision. lean—Producing the maximum sellable products or services at the lowest operational cost while optimizing inventory levels and eliminating waste. lean enterprise—A manufacturing company organized to eliminate all unproductive effort and unnecessary investment, both on the shop floor and in office functions. lean manufacturing/production—An initiative focused on eliminating all waste in manufacturing processes. Principles of lean manufacturing include zero waiting time, zero inventory, scheduling (internal customer pull instead of push system), batch to flow (cut batch sizes), line balancing, and cutting actual process times. The production systems are characterized by optimum automation, just-in-time supplier delivery disciplines, quick changeover times, high levels of quality, and continuous improvement. lean migration—The journey from traditional manufacturing methods to one in which all forms of waste are systematically eliminated. linearity—Refers to measurements being statistically different from one end of the measurement space to the other. For example, a measurement process may be very capable of measuring small parts but much less accurate measuring large parts, or one end of a long part can be measured more accurately than the other.3 H1493 Ramu_p00i-284.indd 249 7/13/16 5:56 PM 250 Glossary lot—A defined quantity of product accumulated under conditions considered uniform for sampling purposes. lot, batch—A definite quantity of some product manufactured under conditions of production that are considered uniform. lot quality—The value of percentage defective or of defects per hundred units in a lot. lot size (also referred to as N)—The number of units in a lot. lower control limit (LCL)—Control limit for points below the central line in a control chart. M maintainability—The probability that a given maintenance action for an item under given usage conditions can be performed within a stated time interval when the maintenance is performed under stated conditions using stated procedures and resources. Malcolm Baldrige National Quality Award (MBNQA)—An award established by the U.S. Congress in 1987 to raise awareness of quality management and recognize U.S. companies that have implemented successful quality management systems. Awards can be given annually in six categories: manufacturing, service, small business, education, healthcare, and nonprofit. The award is named after the late Secretary of Commerce Malcolm Baldrige, a proponent of quality management. The U.S. Commerce Department's National Institute of Standards and Technology manages the award, and ASQ administers it. Master Black Belt (MBB)—Six Sigma or quality expert responsible for strategic implementations in an organization. An MBB is qualified to teach other Six Sigma facilitators the methods, tools, and applications in all functions and levels of the company, and is a resource for using statistical process control in processes. matrix diagram—A planning tool for displaying the relationships among various data sets. mean—A measure of central tendency; the arithmetic average of all measurements in a data set. mean time between failures (MTBF)—The average time interval between failures for repairable product for a defined unit of measure; for example, operating hours, cycles, and miles. measure—The criteria, metric, or means to which a comparison is made with output. measurement—The act or process of quantitatively comparing results with requirements. median—The middle number or center value of a set of data in which all the data are arranged in sequence. H1493 Ramu_p00i-284.indd 250 7/13/16 5:56 PM Glossary 251 metric—A standard for measurement. MIL-STD-105E—A military standard that describes the sampling procedures and tables for inspection by attributes. mistake-proofing—Use of production or design features to prevent the manufacture or passing downstream of a nonconforming product; also known as error-proofing. mode—The value occurring most frequently in a data set. muda—Japanese for waste; any activity that consumes resources but creates no value for the customer. multivariate control chart—A control chart for evaluating the stability of a process in terms of the levels of two or more variables or characteristics. multivoting—Typically used after brainstorming, multivoting narrows a large list of possibilities to a smaller list of the top priorities (or to a final selection) by allowing items to be ranked in importance by participants. Multivoting is preferable to straight voting because it allows an item that is favored by all, but not the top choice of any, to rise to the top.4 N n—The number of units in a sample. N—The number of units in a population. nominal group technique (NGT)—A technique, similar to brainstorming, used to generate ideas on a particular subject. Team members are asked to silently write down as many ideas as possible. Each member is then asked to share one idea, which is recorded. After all the ideas are recorded, they are discussed and prioritized by the group. nonconformity—The nonfulfillment of a specified requirement. nondestructive testing and evaluation (NDT, NDE)—Testing and evaluation methods that do not damage or destroy the product being tested. nonlinear parameter estimation—A method whereby the arduous and laborintensive task of multiparameter model calibration can be carried out automatically under the control of a computer. nonparametric tests—All tests involving ranked data (data that can be put in order). Nonparametric tests are often used in place of their parametric counterparts when certain assumptions about the underlying population are questionable. For example, when comparing two independent samples, the Wilcoxon Mann-Whitney test (see entry) does not assume that the difference between the samples is normally distributed, whereas its parametric counterpart, the two-sample t-test, does. Nonparametric tests can be, and often are, more powerful in detecting population differences when certain assumptions are not satisfied. H1493 Ramu_p00i-284.indd 251 7/13/16 5:56 PM 252 Glossary non-value-added—A term that describes a process step or function that is not required for the direct achievement of process output. This step or function is identified and examined for potential elimination. Also see value-added. normal distribution (statistical)—The charting of a data set in which most of the data points are concentrated around the average (mean), thus forming a bellshaped curve. O occurrence—The likelihood of a cause resulting in the occurrence of a failure mode. This may be based on historical data with other similar processes (usually a scale of 1–5 or 1–10). operating characteristic curve (OC curve)—A graph to determine the probability of accepting lots as a function of the lots' or processes' quality level when using various sampling plans. There are three types: type A curves, which give the probability of acceptance for an individual lot coming from finite production (will not continue in the future); type B curves, which give the probability of acceptance for lots coming from a continuous process; and type C curves, which (for a continuous sampling plan) give the long-run percentage of product accepted during the sampling phase. operations—Work or steps to transform raw materials to finished product. out of spec—A term that indicates a unit does not meet a given requirement or specification. out-of-control process—A process in which the statistical measure being evaluated is not in a state of statistical control. In other words, the variations among the observed sampling results can not be attributed to a constant system of chance causes. Also see in-control process. outputs—Products, materials, services, or information provided to customers (internal or external), from a process. P paired-comparison tests—Examples are two-mean, equal variance t-test; twomean, unequal variance t-test; paired t-test; and F-test. Pareto chart—A graphical tool for ranking causes from most significant to least significant. It is based on the Pareto principle, which was first defined by Joseph M. Juran in 1950. The principle, named after 19th-century economist Vilfredo Pareto, suggests that most effects come from relatively few causes; that is, 80 percent of the effects come from 20 percent of the possible causes. One of the "seven tools of quality." parts per million (ppm)—A method of stating the performance of a process in terms of actual nonconforming material, which can include rejected, returned, or suspect material in the calculation. H1493 Ramu_p00i-284.indd 252 7/19/16 5:02 PM Glossary 253 p-chart—See percent chart. percent chart—A control chart for evaluating the stability of a process in terms of the percentage of the total number of units in a sample in which an event of a given classification occurs. Also referred to as a proportion chart. plan–do–check–act (PDCA) cycle—A four-step process for quality improvement. In the first step (plan), a way to effect improvement is developed. In the second step (do), the plan is carried out, preferably on a small scale. In the third step (check), a study takes place comparing what was predicted and what was observed in the previous step. In the last step (act), action is taken on the causal system to effect the desired change. The plan–do–check–act cycle is sometimes referred to as the Shewhart cycle, because Walter A. Shewhart discussed the concept in his book Statistical Method from the Viewpoint of Quality Control, and as the Deming cycle, because W. Edwards Deming introduced the concept in Japan. The Japanese subsequently called it the Deming cycle. Also called the plan–do–study–act (PDSA) cycle. point of use—A technique that ensures people have exactly what they need to do their jobs—work instructions, parts, tools, and equipment—where and when they need them. Poisson distribution—A discrete probability distribution that expresses the probability of a number of events occurring in a fixed time period if these events occur with a known average rate and are independent of the time since the last event. poka-yoke—Japanese term that means mistake-proofing. A poka-yoke device is one that prevents incorrect parts from being made or assembled, or easily identifies a flaw or error. positional variation—Type of variation frequently within-piece, but can also include machine-to-machine variation, line-to-line or plant-to-plant variation, within-batch variation, and test positioning variation.3 Pp (process performance index)—An index describing process performance in relation to specified tolerance.2 Ppk (minimum process performance index)—The smaller of upper process performance index and lower process performance index.2 practical significance—At least as important as the question of statistical significance, practical or economic significance determines whether an observed sample difference is large enough to be of practical interest. precision—The aspect of measurement that addresses repeatability or consistency when an identical item is measured several times. prevention cost—The cost incurred by actions taken to prevent a nonconformance from occurring; one element of cost of quality or cost of poor quality. preventive action—Action taken to remove or improve a process to prevent potential future occurrences of a nonconformance. H1493 Ramu_p00i-284.indd 253 7/13/16 5:56 PM 254 Glossary prioritization matrix—An L-shaped matrix that uses pairwise comparisons of a list of options to a set of criteria in order to choose the best option(s). First, the importance of each criterion is decided. Then, each criterion is considered separately, with each option rated for how well it meets the criterion. Finally, all the ratings are combined for a final ranking of options. Numerical calculations ensure a balance between the relative importance of the criteria and the relative merits of the options.4 probability (statistical)—The likelihood of occurrence of an event, action, or item. procedure—The steps in a process and how these steps are to be performed for the process to fulfill a customer's requirements; usually documented. process—A set of interrelated work activities characterized by a set of specific inputs and value-added tasks that make up a procedure for a set of specific outputs. process average quality—Expected or average value of process quality. process capability—A statistical measure of the inherent process variability of a given characteristic. The most widely accepted formula for process capability is six sigma. process capability index—The value of the inherent tolerance specified for the characteristic divided by the process capability. The several types of process capability indices include the widely used Cpk and Cp. process control—The method for keeping a process within boundaries; the act of minimizing the variation of a process. process decision program charts (PDPC)—A variant of tree diagrams, a PDPC can be used as a simple alternative to FMEA.3 process flow diagram—A depiction of the flow of materials through a process, including any rework or repair operations; also called a process flow chart. process improvement—The application of the plan–do–check–act cycle (see entry) to processes to produce positive improvement and better meet the needs and expectations of customers. process management—The pertinent techniques and tools applied to a process to implement and improve process effectiveness, hold the gains, and ensure process integrity in fulfilling customer requirements. process map—A type of flowchart depicting the steps in a process and identifying responsibility for each step and key measures. process owner—The person who coordinates the various functions and work activities at all levels of a process, has the authority or ability to make changes in the process as required, and manages the entire process cycle to ensure performance effectiveness. process performance management—The overseeing of process instances to ensure their quality and timeliness; can also include proactive and reactive actions to ensure a good result. H1493 Ramu_p00i-284.indd 254 7/13/16 5:56 PM Glossary 255 process quality—The value of percentage defective or of defects per hundred units in product from a given process. Note: The symbols "p" and "c" are commonly used to represent the true process average in fraction defective or defects per unit, and "l00p" and "100c" the true process average in percentage defective or in defects per hundred units. production part approval process (PPAP)—A "Big Three" automotive process that defines the generic requirements for approval of production parts, including production and bulk materials. Its purpose is to determine during an actual production run at the quoted production rates whether all customer engineering design record and specification requirements are properly understood by the supplier and that the process has the potential to produce product consistently meeting these requirements. program evaluation and review technique (PERT) charts—Developed during the Nautilus submarine program in the 1950s, a PERT chart resembles an activity network diagram in that it shows task dependencies. It calculates best, average, and worst expected completion times.3 project management—The application of knowledge, skills, tools, and techniques to a broad range of activities to meet the requirements of a particular project. project team—Manages the work of a project. The work typically involves balancing competing demands for project scope, time, cost, risk, and quality, satisfying stakeholders with differing needs and expectations, and meeting identified requirements. proportion chart—See percent chart. pull system—An alternative to scheduling individual processes in which the customer process withdraws the items it needs as at a supermarket, and the supplying process produces to replenish what was withdrawn; used to avoid push. Also see kanban. Q quality—A subjective term for which each person or sector has its own definition. In technical usage, quality can have two meanings: 1. the characteristics of a product or service that bear on its ability to satisfy stated or implied needs; 2. a product or service free of deficiencies. According to Joseph M. Juran, quality means "fitness for use"; according to Philip Crosby, it means "conformance to requirements." quality assurance/quality control (QA/QC)—Two terms that have many interpretations because of the multiple definitions for the words "assurance" and "control." For example, "assurance" can mean the act of giving confidence, the state of being certain, or the act of making certain; "control" can mean an evaluation to indicate needed corrective responses, the act of guiding, or the state of a process in which the variability is attributable to a constant system of chance causes. (For a detailed discussion on the multiple definitions, see ANSI/ISO/ASQ A3534-2, Statistics—Vocabulary and symbols—Statistical quality H1493 Ramu_p00i-284.indd 255 7/13/16 5:56 PM 256 Glossary control.) One definition of quality assurance is: all the planned and systematic activities implemented within the quality system that can be demonstrated to provide confidence that a product or service will fulfill requirements for quality. One definition for quality control is: the operational techniques and activities used to fulfill requirements for quality. Often, however, "quality assurance" and "quality control" are used interchangeably, referring to the actions performed to ensure the quality of a product, service, or process. quality audit—A systematic, independent examination and review to determine whether quality activities and related results comply with plans and whether these plans are implemented effectively and are suitable to achieve the objectives. quality costs—See cost of poor quality. quality function deployment (QFD)—A structured method in which customer requirements are translated into appropriate technical requirements for each stage of product development and production. The QFD process is often referred to as listening to the voice of the customer. quality loss function—A parabolic approximation of the quality loss that occurs when a quality characteristic deviates from its target value. The quality loss function is expressed in monetary units: the cost of deviating from the target increases quadratically the farther the quality characteristic moves from the target. The formula used to compute the quality loss function depends on the type of quality characteristic being used. The quality loss function was first introduced in this form by Genichi Taguchi. quality management (QM)—The application of a quality management system in managing a process to achieve maximum customer satisfaction at the lowest overall cost to the organization while continuing to improve the process. quality management system (QMS)—A formalized system that documents the structure, responsibilities, and procedures required to achieve effective quality management. queue time—The time a product spends in a line awaiting the next design, order processing, or fabrication step. quick changeover—The ability to change tooling and fixtures rapidly (usually within minutes) so multiple products can be run on the same machine. R random cause—A cause of variation due to chance and not assignable to any factor. random sampling—A commonly used sampling technique in which sample units are selected so all combinations of n units under consideration have an equal chance of being selected as the sample. range (statistical)—The measure of dispersion in a data set (the difference between the highest and lowest values). H1493 Ramu_p00i-284.indd 256 7/13/16 5:56 PM Glossary 257 range chart (R chart)—A control chart in which the subgroup range R evaluates the stability of the variability within a process. rational subgrouping—Subgrouping wherein the variation is presumed to be only from random causes.2 regression analysis—A statistical technique for determining the best mathematical expression describing the functional relationship between one response variable and one or more independent variables. relations diagram—See interrelationship diagram. reliability—The probability of a product's performing its intended function under stated conditions without failure for a given period of time. repeatability—The variation in measurements obtained when one measurement device is used several times by the same person to measure the same characteristic on the same product. reproducibility—The variation in measurements made by different people using the same measuring device to measure the same characteristic on the same product. requirements—The ability of an item to perform a required function under stated conditions for a stated period of time. risk management—Using managerial resources to integrate risk identification, risk assessment, risk prioritization, development of risk handling strategies, and mitigation of risk to acceptable levels. risk priority number (RPN)—The product of the severity, occurrence, and detection values determined in FMEA. The higher the RPN, the more significant the failure mode. robustness—The condition of a product or process design that remains relatively stable, with a minimum of variation, even though factors that influence operations or usage, such as environment and wear, are constantly changing. root cause—A factor that caused a nonconformance and should be permanently eliminated through process improvement. run chart—A chart showing a line connecting numerous data points collected from a process running over time. S sample—In acceptance sampling, one or more units of product (or a quantity of material) drawn from a lot for purposes of inspection to reach a decision regarding acceptance of the lot. sample size (n)—The number of units in a sample. sample standard deviation chart (s-chart)—A control chart in which the subgroup standard deviation s is used to evaluate the stability of the variability within a process. H1493 Ramu_p00i-284.indd 257 7/13/16 5:56 PM 258 Glossary scatter diagram—A graphical technique to analyze the relationship between two variables. Two sets of data are plotted on a graph, with the y-axis being used for the variable to be predicted and the x-axis being used for the variable to make the prediction. The graph will show possible relationships (although two variables might appear to be related, they might not be; those who know most about the variables must make that evaluation). One of the "seven tools of quality." seven tools of quality—Tools that help organizations understand their processes to improve them. The tools are the cause-and-effect diagram, check sheet, control chart, flowchart, histogram, Pareto chart, and scatter diagram. seven wastes—See eight wastes. severity—The severity of the failure mode is based on the worst-case effect of the failure mode. Severity may range from safety concern (very high) to no effect (very low) (usually a scale of 1-5 or 1-10). Shewhart cycle—See plan–do–check–act cycle. sigma—One standard deviation in a normally distributed process. single-piece flow—A process in which products proceed one complete product at a time, through various operations in design, order taking, and production without interruptions, backflows, or scrap. SIPOC diagram—A tool used by Six Sigma process improvement teams to identify all relevant elements (suppliers, inputs, process, outputs, customers) of a process improvement project before work begins. Six Sigma—A method that provides organizations tools to improve the capability of their business processes. This increase in performance and decrease in process variation lead to defect reduction and improvement in profits, employee morale, and quality of products or services. Six Sigma quality is a term generally used to indicate that a process is well controlled (±6σ from the centerline in a control chart). six sigma quality—A term generally used to indicate process capability in terms of process spread measured by standard deviations in a normally distributed process. special causes—Causes of variation that arise because of special circumstances. They are not an inherent part of a process. Special causes are also referred to as assignable causes. Also see common causes. specification—A document that states the requirements to which a given product or service must conform. stages of team growth—Four stages that teams move through as they develop maturity: forming, storming, norming, and performing. standard deviation (statistical)—A computed measure of variability indicating the spread of the data set around the mean. standard work—A precise description of each work activity, specifying cycle time, takt time, the work sequence of specific tasks, and the minimum inventory of H1493 Ramu_p00i-284.indd 258 7/13/16 5:56 PM Glossary 259 parts on hand needed to conduct the activity. All jobs are organized around human motion to create an efficient sequence without waste. Work organized in such a way is called standard(ized) work. The three elements that make up standard work are takt time, working sequence, and standard in-process stock. standard work instructions—A lean manufacturing tool that enables operators to observe a production process with an understanding of how assembly tasks are to be performed. It ensures that the quality level is understood and serves as an excellent training aid, enabling replacement or temporary individuals to easily adapt and perform the assembly operation. statistical process control (SPC)—The application of statistical techniques to control a process; often used interchangeably with the term statistical quality control. statistical quality control (SQC)—The application of statistical techniques to control quality. Often used interchangeably with the term statistical process control, although statistical quality control includes acceptance sampling, which statistical process control does not. statistical significance—Level of accuracy expected of an analysis of data. Most frequently it is expressed as either a "95 percent level of significance" or "five percent confidence level."5 strengths, weaknesses, opportunities, threats (SWOT) analysis—A strategic technique used to assess an organization's competitive position. Student's t-distribution—A continuous distribution of the ratio of two independent random variables—a standard normal and a chi-square.1 supplier—A source of materials, service, or information input provided to a process. supplier quality assurance—Confidence that a supplier's product or service will fulfill its customers' needs. This confidence is achieved by creating a relationship between the customer and supplier that ensures that the product will be fit for use with minimal corrective action and inspection. According to Joseph M. Juran, nine primary activities are needed: (1) define product and program quality requirements, (2) evaluate alternative suppliers, (3) select suppliers, (4) conduct joint quality planning, (5) cooperate with the supplier during the execution of the contract, (6) obtain proof of conformance to requirements, (7) certify qualified suppliers, (8) conduct quality improvement programs as required, (9) create and use supplier quality ratings. supply chain—The series of suppliers to a given process. system—A group of interdependent processes and people that together perform a common mission. T Taguchi methods—The American Supplier Institute's trademarked term for the quality engineering methodology developed by Genichi Taguchi. In this H1493 Ramu_p00i-284.indd 259 7/13/16 5:56 PM 260 Glossary e ngineering approach to quality control, Taguchi calls for off-line quality control, online quality control, and a system of experimental design to improve quality and reduce costs. takt time—The rate of customer demand, takt time is calculated by dividing production time by the quantity of product the customer requires in that time. Takt is the heartbeat of a lean manufacturing system. Also see cycle time. team—A group of individuals organized to work together to accomplish a specific objective. Also see stages of team growth. temporal variation—The time-to-time or shift-to-shift variation—that is, variation across time.3 theory of constraints (TOC)—A lean management philosophy that stresses removal of constraints to increase throughput while decreasing inventory and operating expenses. TOC's set of tools examines the entire system for continuous improvement. The current reality tree, conflict resolution diagram, future reality tree, prerequisite tree, and transition tree are the five tools used in TOC's ongoing improvement process. Also called constraints management. throughput—The rate at which the system generates money through sales, or the conversion rate of inventory into shipped product. tolerance—The maximum and minimum limit values a product can have and still meet customer requirements. total productive maintenance (TPM)—A series of methods, originally pioneered by Nippondenso (a member of the Toyota group), to ensure that every machine in a production process is always able to perform its required tasks so production is never interrupted. total quality management (TQM)—A term coined by the Naval Air Systems Command to describe its Japanese-style management approach to quality improvement. Since then, TQM has taken on many meanings. Simply put, it is a management approach to long-term success through customer satisfaction. TQM is based on all members of an organization participating in improving processes, products, services, and the culture in which they work. The methods for implementing this approach are found in the teachings of such quality leaders as Philip B. Crosby, W. Edwards Deming, Armand V. Feigenbaum, Kaoru Ishikawa, and Joseph M. Juran. Toyota Production System (TPS)—The production system developed by Toyota Motor Corp. to provide best quality, lowest cost, and shortest lead time through eliminating waste. TPS is based on two pillars: just-in-time and jidoka. TPS is maintained and improved through iterations of standardized work and kaizen. tree diagram—A management tool that depicts the hierarchy of tasks and subtasks needed to complete an objective. The finished diagram bears a resemblance to a tree. trend—The graphical representation of a variable's tendency, over time, to increase, decrease, or remain unchanged. H1493 Ramu_p00i-284.indd 260 7/13/16 5:56 PM Glossary 261 trend control chart—A control chart in which the deviation of the subgroup average, x-, from an expected trend in the process level is used to evaluate the stability of a process. TRIZ—A Russian acronym for a theory of innovative problem solving. t-test—A method to assess whether the means of two groups are statistically different from each other. type I error—An incorrect decision to reject something (such as a statistical hypothesis or a lot of products) when it is acceptable. type II error—An incorrect decision to accept something when it is unacceptable. U u-chart—Count-per-unit chart. unit—An object for which a measurement or observation can be made; commonly used in the sense of a "unit of product," the entity of product inspected to determine whether it is defective or nondefective. upper control limit (UCL)—Control limit for points above the central line in a control chart. V validation—The act of confirming that a product or service meets the requirements for which it was intended. validity—The ability of a feedback instrument to measure what it was intended to measure; also, the degree to which inferences derived from measurements are meaningful. value stream—All activities, both value-added and non-value-added, required to bring a product from raw material state into the hands of the customer, bring a customer requirement from order to delivery, and bring a design from concept to launch. Also see hoshin planning. value stream mapping—A pencil and paper tool used in two stages. First, follow a product's production path from beginning to end and draw a visual representation of every process in the material and information flows. Second, draw a future state map of how value should flow. The most important map is the future state map. value-added—A term used to describe activities that transform input into a customer (internal or external)–usable output. variables (attributes) data—Measurement information. Control charts based on variables data include average (x–) chart, range (R) chart, and sample standard deviation (s) chart. variation—A change in data, characteristic, or function caused by one of four factors: special causes, common causes, tampering, or structural variation. H1493 Ramu_p00i-284.indd 261 7/13/16 5:56 PM 262 Glossary verification—The act of determining whether products and services conform to specific requirements. voice of the customer—The expressed requirements and expectations of customers relative to products or services, as documented and disseminated to the providing organization's members. W waste—Any activity that consumes resources and produces no added value to the product or service a customer receives. Also known as muda. Wilcoxon Mann-Whitney test—Used to test the null hypothesis that two populations have identical distribution functions against the alternative hypothesis that the two distribution functions differ only with respect to location (median), if at all. It does not require the assumption that the differences between the two samples are normally distributed. In many applications, it is used in place of the two sample t-test when the normality assumption is questionable. This test can also be applied when the observations in a sample of data are ranks, that is, ordinal data, rather than direct measurements. X x bar (x–) chart—Average chart. Z zero defects—A performance standard and method Philip B. Crosby developed, which states that if people commit themselves to watching details and avoiding errors, they can move closer to the goal of zero defects. Endnotes Source: Except where noted, definitions reproduced with permission of ASQ, . 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